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ARE "SUPERWEEDS" AN OUTGROWTH OF USDA BIOTECH POLICY? (PART II)

HEARING

BEFORE THE

SUBCOMMITTEE ON DOMESTIC POLICY

OF THE

COMMITTEE ON OVERSIGHT AND GOVERNMENT REFORM

HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

SECOND SESSION

SEPTEMBER 30, 2010

Serial No. 111–160

Printed for the use of the Committee on Oversight and Government Reform



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ARE "SUPERWEEDS" AN OUTGROWTH OF USDA BIOTECH POLICY? (PART II)

THURSDAY, SEPTEMBER 30, 2010

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON DOMESTIC POLICY,
COMMITTEE ON OVERSIGHT AND GOVERNMENT REFORM,
Washington, DC.

The subcommittee met, pursuant to notice, at 2:04 p.m., in room 2203, Rayburn House Office Building, Hon. Dennis J. Kucinich (chairman of the subcommittee) presiding.

Present: Representatives Kucinich, Watson, and Towns.

Staff present: Jaron R. Bourke, staff director; and Justin Baker, clerk/policy analyst.

Mr. KUCINICH. Good afternoon. The subcommittee will come to order. I want to note that usually we're joined by many Members of Congress, but late last night they had a get-out-of-dodge moment. And most Members are now back in their home constituency, a place that I intend to be in a few hours. But I am very pleased that all of you are here for this important hearing. The Subcommittee on Domestic Policy on the Committee on Oversight and Government Reform is now in order.

Today's hearing is the second day of the first hearing held by Congress to examine the environmental impact of the evolution of herbicide-resistant weeds in fields growing genetically engineered herbicide resistant crops. But for years, farmers have struggled with the impact. Across the Midwest and south, farmers growing Roundup Ready soy, corn and cotton have been encountering more and more kinds of weeds that Roundup herbicide cannot control.

That weed resistance costs farmers money and causes them to resort to more and more toxic pesticides. Please look at the monitors for an excerpt from an ABC News segment that ran last year. Staff, play that segment.

[Video shown.]

Mr. KUCINICH. Thank you. What responsibility for preventing and lessening the environmental impact of Roundup-resistant weeds and the consequent impact on farmers does the Federal Government have? Today we will hear from government regulators and others on that question. Now without objection, I'm going to continue with an opening statement of 5 minutes, any Member or witness who wishes to submit a written statement or extraneous materials for the record will have 5 legislative days to do so, without objection.

And in our previous hearing in July, we heard from weed scientists that Roundup-resistant weeds have infested between 4 and 11 million acres of prime farmland in the southeast and Midwest.

Mr. Chairman, welcome. This is the chairman of the full committee, Mr. Towns. Thank you for being here.

While a phenomenon of natural selection for herbicide resistant—resistance is not new, the acceleration in a number of resistant weed species, and especially the infested acreage, is new. And it's been caused by the commercialization of multiple Roundup-resistant crop systems. In only the last decade, eight or nine species of weeds have rapidly evolved resistance to Roundup in herbicide resistant crop fields. Indeed, Roundup resistance in weeds has been known since the year 2000 when Roundup-resistant horseweed, a weed species that had not been previously resistant to Roundup, was discovered in Roundup-Ready crop fields in Delaware.

While scientists have validated what farmers were discovering in their fields, the Nation's lead regulator of genetically engineered crops, the U.S. Department of Agriculture, has been looking the other way. Every time a pesticide company petitioned the USDA to deregulate a new herbicide-tolerant variety of crop, USDA determined that the introduction of the new crop would have "No significant impact" on the farming environment. But recently the Department's indifference to the indirect consequences of their deregulation of Roundup-resistant crops has caught the attention of two Federal District Court judges. They independently struck down the USDA's deregulation of Roundup-Ready alfalfa, and Roundup-Ready sugar beets.

They found USDA to have unreasonably and arbitrarily dismiss the environmental consequences of deregulating genetically engineered crops. In one instance, the judge found that USDA could produce no written record that it had ever considered the impact on farmers. Nevertheless, Roundup-resistant weeds are hurting farmers. They are imposing $1 billion in additional weed control costs. They threaten cotton growing so profoundly that they've been compared to the boll weevil.

And the solution may be worse than the problem. To combat Roundup-resistant weed proliferation, the pesticide industry recommends to farmers that they use more and more toxic pesticides on newly engineered crops that will be tolerant of those more toxic pesticides. That will surely lead to more environmental pollution, and, as we shall see, the collateral damage of crop destruction, and even more costs to farmers.

In today's hearing, we will show that the USDA's passivity lies in stark contrast to the EPA's active approach in preventing pest resistance to genetically engineered crops it regulates. We will show that the USDA's legal authority is no less broad than EPA's legal authority. However, USDA views its broad authority much too narrowly, while EPA used its broad authority appropriately.

Which approach has the better track record? Passive and self-constrained, USDA's approach has plainly allowed the proliferation of herbicide-resistant weeds. In contrast, EPA's record of prevention is a relative success.

Perhaps we are at a crossroads for USDA's policy of passivity toward superweeds, having been reversed by two Federal judges with

scores of farmers needing relief from the cost and consequences of superweeds. And with a new administration determining policy at the Department, it may finally be the time there for the Department of Agriculture to reexamine its approach to the deregulation of the genetically engineered crops, and to make a change in policy.

It should be a change that would help prevent the proliferation of herbicide resistant weeds. It should be a change that would preserve efficacy of a relatively benign herbicide. It should be a change that would deescalate the trend to more and more toxic pesticides. It should be a change that would pass muster with Federal courts. It should be a change that would protect the long-term interest of farmers, consumers and the natural environment.

The chair recognizes the distinguished chair of the full committee, Mr. Towns of New York. I appreciate your being here, Mr. Towns, and I appreciate the leadership that you provide on the full committee.

[The prepared statement of Hon. Dennis J. Kucinich follows:]

Opening Statement of

Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee
Oversight and Government Reform Committee

Hearing on

"Are 'Superweeds' an Outgrowth of USDA Biotech Policy? (Part II)"

September 30, 2010

In our previous hearing in July, we heard from weed scientists that Roundup resistant weeds have infested between 4 and 11 million acres of prime farmland in the Southeast and Midwest. While the phenomenon of natural selection for herbicide resistance is not new, the acceleration in the number of resistant weed species and especially the infested acreage is new, and it has been caused by the commercialization of multiple Roundup resistant crop systems. In only the last decade, eight or nine species of weeds have rapidly evolved resistance to Roundup in herbicide-resistant crop fields. Indeed, Roundup resistance in weeds has been known since 2000, when Roundup resistant horseweed, a weed species that had not been previously resistant to Roundup, was discovered in Roundup Ready crop fields in Delaware.

While scientists have validated what farmers were discovering in their fields, the nation's lead regulator of genetically engineered crops, the U.S. Department of Agriculture, has been looking the other way. Every time a pesticide company petitioned USDA to deregulate a new herbicide tolerant variety of crop, USDA determined that the introduction of the new crop would have "no significant impact" on the farming environment. But recently, the Department's indifference to the indirect consequences of their deregulation of Roundup resistant crops has caught the attention of two federal district court judges. They independently struck down USDA's deregulation of Roundup Ready Alfalfa and Roundup Ready Sugar beets. They found USDA to have unreasonably and arbitrarily dismissed the environmental consequences of deregulating genetically engineered crops. In one instance, the judge found that USDA could produce no written record that it had ever even considered the impact on farmers.

Nevertheless, Roundup resistant weeds are hurting farmers. They are imposing a billion dollars in additional weed control costs. They threaten cotton growing so profoundly that they have been compared to the boll weevil. And the solution may be worse than the problem. To combat Roundup resistant weed proliferation, the pesticide industry recommends to farmers that they use more and more toxic pesticides, on newly engineered crops that will be tolerant of those more toxic pesticides. That will surely

lead to more pollution and, as we shall see, the collateral damage of crop destruction and even more costs on farmers.

In today's hearing, we will show that USDA's passivity lies in stark contrast to EPA's active approach in preventing pest resistance to genetically engineered crops it regulates. We will show that USDA's legal authority is no less broad than EPA's legal authority. However, USDA views its broad authority much too narrowly, while EPA views its broad authority appropriately.

Which approach has a better track record? Passive and self-constrained, USDA's approach has plainly allowed the proliferation of herbicide resistant weeds. In contrast, EPA's record of prevention is a relative success.

Perhaps we are at a crossroads for USDA's policy of passivity toward superweeds. Having been reversed by two federal courts, with scores of farmers needing relief from the costs and consequences of superweeds, and with a new administration determining policy at the Department, it may finally be time for the Department of Agriculture to reexamine its approach to the regulation of genetically engineered crops and to make a change in policy.

It should be a change that would help prevent the proliferation of herbicide resistant weeds.

It should be a change that would preserve efficacy of a relatively benign herbicide.

It should be a change that would de-escalate the trend to more and more toxic pesticides.

It should be a change that would pass muster with federal courts.

It should be a change that would protect the long term interests of farmers, consumers and the natural environment.

Mr. TOWNS. I want to thank you, first of all, for holding this hearing. I want to thank the witnesses for being here. And I know that you realize the importance of it because the Congress is not even in session, and of course this hearing is still taking place because of the importance of it. And of course, I want to just thank my colleague for moving forward with it because, let's face it, this is a very, very important hearing and I think that sometimes we forget all about it in terms of how important it is in terms of farming and something that we sort of pushed aside.

I think it was Mr. Louis Perry, a cotton grower in Georgia whose family has been farming since 1830, told a reporter that herbicide resistant pigweed posed a lethal threat to cotton farming in Georgia. I mean, it talks about in terms of how important it is, so if we don't whip this thing, it's going to be like the boll weevil as it was pointed out. Of course, we have to make certain that we stay on top of it and stay focused.

I want to thank the gentleman who comes from an urban area that understands how important this is and spending time and focusing on it. So I want to let you know that from the full committee standpoint, we stand ready to support you in every way, but I'm happy to know that you're getting the message out, because it's important that we do so.

So again, thank you for taking time to be here even when the House is not in session, because you felt it was important to continue without cancellation and I want to salute you for that. Thank you and I yield back.

Mr. KUCINICH. Thank you very much for being here, Mr. Chairman. I want you to know that—well, it's true that I'm in a primarily urban area. There are a few small farms in the southern part of my district. But I became aware of this, in part, through meeting with farmers across the country during the time that I was campaigning nationally for the Democratic nomination. So I have had the chance to actually be on farms, talk to farmers about their concerns about the issues that are raised in this hearing today.

There are no additional opening statements, so our subcommittee is going to receive testimony from the witnesses before us today. I would like to start by introducing our panel. The Honorable Ann Wright, Deputy Under Secretary for marketing and regulatory programs at the U.S. Department of Agriculture. Previously, she served as senior policy advisor to Senate Majority Leader Harry Reid, on Agriculture Committee matters. Before joining the staff of Senator Reid, she was a lobbyist for Consumer's Union on energy and trade issues. Previously she worked with farmers and nonprofit organizations at the Sustainable Agriculture Coalition in Washington, DC, and served as a policy advisor on agriculture issues for Senator Paul Wellstone of Minnesota and Senator Paul Simon of Illinois.

Mr. Sid Abel, is the assistant deputy administrator for biotechnology regulatory service with the U.S. Department of Agriculture's Animal and Plant Health Inspection Service. In this role, he helps provide oversight of risk-based introductions of regulated genetically engineered biotechnology crops, as well as conducting

and providing oversight of broad environmental risk and impact assessments complaint with the National Environmental Policy Act.

Prior to this, he served as the associate director with the U.S. Environmental Protection Agency's Office of Pesticide Programs. He worked for the EPA in various capacities from 1989 to 2007. Mr. Abel will not deliver testimony, but will be available to answer subcommittee members' questions.

The Honorable James J. Jones is the principal deputy assistant administrator of the EPA's Office of Chemical Safety and Pollution Prevention. He is responsible for managing the day-to-day operations of the office, which implements the Nation's pesticide toxic chemical and pollution prevention laws. The Office has an annual budget of over $260 million, more than 1,200 employees. From 2003 to 2007 Mr. Jones served as a director of the office of pesticide programs. In this role he was responsible for the regulation of pesticides in the United States with a budget of approximately $150 million and 815 employees, making it the largest EPA headquarters program office. I want to thank each of the witnesses for appearing before the subcommittee.

It is the policy of our Committee on Oversight and Government Reform to swear in all witnesses before they testify. Now Mr. Able, even though you're not making an opening statement, I'm going to ask if you would agree to be sworn because your answers to your questions will put your testimony on the record. And I would ask that all the witnesses rise.

[Witnesses sworn.]

Mr. KUCINICH. Let the record reflect that each of the witnesses has answered in the affirmative.

I ask that each witness give an oral summary of his or her testimony to keep the summary under 5 minutes in duration. Your complete written statement is going to be included in the record. So what we want in 5 minutes is to try to get a sense of what you want to communicate to this committee. I would like to begin with Ann Wright, the first witness on the panel, please begin.

STATEMENTS OF ANN WRIGHT, DEPUTY UNDER SECRETARY, U.S. DEPARTMENT OF AGRICULTURE; SID ABEL, ASSISTANT DEPUTY ADMINISTRATOR, BIOTECHNOLOGY REGULATORY SERVICE, ANIMAL AND PLANT HEALTH INSPECTION SERVICE, U.S. DEPARTMENT OF AGRICULTURE; AND JIM JONES, DEPUTY ASSISTANT ADMINISTRATOR, OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION, U.S. ENVIRONMENTAL PROTECTION AGENCY

STATEMENT OF ANN WRIGHT

Ms. WRIGHT. Thank you, Mr. Chairman and Mr. Chairman. I appreciate the opportunity to be here today to discuss USDA's biotechnology regulatory programs and the issue of herbicide-resistant weeds. First, I would like to emphasize that at USDA, we support all forms of agriculture, including conventional, genetically engineered and organic crops to meet the Nation's and world's needs for security, energy production and the economic sustainability of farms. All three of those methods of production must be strong and viable. As the world population increases, the demand for food is

growing and the land available to farm is shrinking. We need innovative agriculture production systems to not only to maintain the competitiveness of the United States, but also to fulfill growing food needs. Biotechnology is just one tool to address those needs, but it's a critical one.

USDA's role in regulating the products of biotechnology is carried out in coordination with EPA and FDA. Through the Plant Protection Act, our animal, plant health inspection service regulates those products that may pose a plant pest risk, while EPA and FDA use their authorities to address the safety of our food supply and the safe use of pesticides.

USDA's biotechnology regulatory program, which has been in place since 1986, is rigorous and science based. Since the program began we have effectively overseen nearly 30,000 field trials at 86,000 locations and deregulated over 75 products. While our current biotechnology regulations have been effective in insuring the safe introduction of GE organisms, we are constantly learning from our experiences, reforming and refining our first rate program to protect American agriculture and the environment.

As part of those refinements, we are always looking at ways to improve our program. Chief among these is our effort to update our biotechnology regulations. USDA is examining the policy issue raised in over 66,000 comments that were submitted on our proposed regulations, with the goal of better positioning the agency to address new challenges while meeting current needs. Our biotechnology program has evolved as the number of environmental issues to be considered under NEPA has grown as well as in response to several NEPA-related lawsuits.

At the same time, it's important to remember that we have made thousands of regulatory decisions without legal challenge, and just as important, not one of our plant pest risk determinations have been overturned in court.

You also asked me to discuss how USDA approaches herbicide-resistant weeds in relation to GE crops. A key point is that while the consideration of the herbicide resistance in weeds under NEPA informs our decisionmaking, and we are fully committed to meeting our NEPA obligations, USDA's biotechnology regulatory decisions are ultimately based on plant pest risk, consistent with our authority under the Plant Protection Act.

It is also important to note that the development of herbicide resistance among weeds is natural and an evolutionary process. It is not exclusively associated with GE crops, and that GE crops provide many benefits, such as reduced pesticide use and decreased soil erosion thanks to no till farming. And we want to preserve those benefits.

We must also be cognizant that if we limit the use of herbicide tolerant crops, farmers will likely have to return to older, less environmentally friendly weed control methods.

Because herbicide resistance is an important issue for the agricultural community, USDA has multiple agencies engaged on the issue through research and education, as well as partnerships with outside groups and other Federal agencies. For instance, our National Institutes of Food and Agriculture's Competitive Grants Pro-

gram provided $4.6 million in 2009 research for the biology of weedy invasive species.

Further NIFA's extension outreach programs provide the connection between scientific research and its application on farms, the training sessions, field days and other outreach to growers.

USDA's Agricultural Research Service has nearly $4.4 million in herbicide resistant weed research in fiscal year 2010, which is part of $36 million it's dedicating to all weed science issues this year. And APHIS is partnered with the EPA and the Weed Science Society of America to better understand the extent of herbicide resistance in managed ecosystems as well as the methods being used to manage herbicide resistance in weeds.

We are fully committed to working with our partners to identify potential solutions and alternative techniques to address herbicide resistance. This will require a coordinated effort by everyone involved, the government, Congress, researchers, the agricultural community, technology and crop protection companies, and public interest groups. At USDA, we are looking at the broader context of herbicide resistance beyond just its relation to biotechnology. We look forward to working with our partners, including all in Congress. Together we are confident that we can find solutions that make sense.

Mr. Chairman, Mr. Chairman, thank you again for the opportunity to testify. I look forward to answering your questions.

[The prepared statement of Ms. Wright follows:]

Testimony of Ms. Ann Wright
Deputy Under Secretary for Marketing and Regulatory Programs
United States Department of Agriculture

Before the Subcommittee on Domestic Policy
of the
House Committee on Oversight and Government Reform

September 30, 2010

Thank you for the opportunity to be here today to discuss the U.S. Department of Agriculture's (USDA) biotechnology regulatory program, as well as the issue of herbicide resistant weeds. I am Ann Wright, Deputy Under Secretary of Marketing and Regulatory Programs. In this capacity, I oversee a broad array of issues within three USDA agencies, including the Animal and Plant Health Inspection Service (APHIS), which, among other things, regulates organisms derived through biotechnology. Additionally, several other USDA agencies are looking at herbicide resistant weed issues and I look forward to updating you on those efforts. Sidney Abel, Assistant Deputy Administrator of APHIS' Biotechnology Regulatory Services program, is joining me today.

First I would like to emphasize that at USDA, we support all forms of agriculture—conventional (including the use of genetically engineered (GE) products) and organic—to meet the nation's and the world's need for food security, energy production, and the economic sustainability of farms. As the world's population increases, the demand for food is growing and the land available to farm is shrinking. Innovation in agricultural production systems is vital to maintain the competitiveness of the U.S. agricultural sector and to help supply the world's food needs. This is why USDA is pursuing policies that promote the coexistence of conventional, organic, and GE crops. USDA believes that our future food security necessitates that all types of agriculture be able to coexist and thrive.

At the same time, it is critical that we ensure our regulatory oversight is consistent, effective, and science-based, that we are keeping pace with the latest scientific developments, and that we do so transparently. As you know, the Plant Protection Act authorizes USDA, through APHIS, to regulate the importation, interstate movement, and safe field testing of GE organisms that may pose a pest risk to plants. In regulating the products of biotechnology, APHIS works closely with the U.S. Food and Drug Administration and the U.S. Environmental Protection Agency (EPA). Together, we ensure that the development, testing, and use of the products of biotechnology occur in a manner that is safe for plant and animal health, human health, and the environment.

In March 2008, APHIS Administrator Cindy Smith updated this Subcommittee on a number of actions the Agency had taken to build a strong program for regulating the products of biotechnology. This included the development of more detailed environmental analyses, increased oversight of pharmaceutical and industrial crops, and the creation of a dedicated staff for compliance and enforcement. Today I would like to update you on more recent initiatives

that we are undertaking with our biotechnology regulatory program, as well as discuss activities we are undertaking to address herbicide resistant weeds.

USDA's Biotechnology Regulatory Program – A Constant Evolution

USDA's biotechnology regulatory program has been in place since 1986, and as I mentioned, we continue to evolve as the field of biotechnology grows and changes. Over time, we have developed a framework for regulating the products of biotechnology that is rigorous and science-based, and which serves as a model globally that encourages the safe and unimpeded trade in these products. Since the program began, APHIS has effectively overseen the safe adoption of products of biotechnology, with 26,000 field trials grown under our notification procedures and 3,000 field tests grown under the permitting process, encompassing field trials at 86,000 different locations. In addition, we have deregulated over 75 products in that time. While our current biotechnology regulations have been effective in ensuring the safe introduction of GE organisms, we're constantly learning from our experiences, reforming, and refining our first-rate program to protect American agriculture and the environment.

The broadest of these efforts is a comprehensive update to our current biotechnology regulations—to better position APHIS to address new challenges, as well as meet current needs in evaluating and addressing the plant pest or noxious weed risks associated with regulated GE organisms. We accepted public comments on the proposed regulatory changes for over 6 months and held 5 public meetings, resulting in over 66,000 public comments by the time the comment period closed last June. Many important policy issues were raised, and USDA's policymakers are currently examining those issues to determine how to proceed. Ultimately, we want to advance a rule that will continue to support innovation in biotechnology in a responsible way that provides farmers and consumers with safe and beneficial options.

In addition to our larger effort to improve our biotechnology regulations, we have made other changes to keep pace with innovation in this growing field. We have welcomed the critical looks taken by the Government Accountability Office and USDA's Inspector General, and have made improvements to our regulatory program consistent with their recommendations. We have addressed the majority of recommendations—many which were in line with ongoing Agency initiatives at the time—through efforts such as requiring additional information on field trials and enhancing tracking of inspections and field test reports.

Additionally, the 2008 Farm Bill included recommendations that APHIS had made and begun implementing in late 2007 to improve the management and oversight of regulated biotechnology products. A number of those recommendations are addressed in our proposed revisions to our biotechnology regulations. Others are ongoing, such as our partnership with the Association of Official Seed Certifying Agencies to examine isolation distances for field trials.

The Farm Bill also directed APHIS to take steps to ensure the quality and completeness of records and to develop standards for quality management and effective research. These and other issues are being addressed through our expanding Biotechnology Quality Management System (BQMS) Program—a voluntary compliance assistance program—to help biotechnology researchers and companies develop plans and manage their operations to comply with USDA's

biotechnology regulatory requirements. The program provides participating organizations with improved management capabilities for regulated activities, and requires internal as well as independent third-party audits to make sure that the quality management system is being followed at all levels of the organization. In 2009, five organizations representing large and small companies and university researchers participated in the BQMS pilot program and helped APHIS refine the program. We are now preparing to implement the refined BQMS program and are soliciting additional organizations to join. We are encouraging broad participation from large and small companies and academic research communities. We are also finalizing the BQMS audit standards and program requirements and have begun training our second cohort of participating organizations.

APHIS' biotechnology program has also evolved as more varied environmental issues have arisen that should be considered under the National Environmental Policy Act (NEPA), as well as in response to several NEPA-related lawsuits on APHIS regulatory decisions. However, it is important to point out that we've made thousands of regulatory decisions without legal challenge, and none of our plant pest determinations have been overturned in court. We have taken these decisions and built into our program process improvements to ensure that we fully document information pertaining to environmental issues so that we meet all environmental requirements.

We have also taken and continue to take other steps to improve the environmental review process within our biotechnology regulatory program. For example, Secretary Vilsack approved a reorganization of APHIS' biotechnology staff that includes the establishment of a new NEPA team that is devoted to preparing high-quality environmental documents to better inform our regulatory decisions.

As we move forward with making future reviews of the potential environmental issues associated with the regulatory requests before the Agency, APHIS will continue to use the best available scientific information, data, and expert advice to prepare the appropriate level of NEPA analysis. We consider each regulatory action on a case-by-case basis, in accordance with Council on Environmental Quality (CEQ) NEPA implementing regulations and the USDA and APHIS NEPA regulations and procedures. And we will continue to consult with EPA on our analyses related to requests to remove products from regulation, which currently include GE alfalfa and sugar beets. In these ongoing consultations, EPA provides valuable feedback to the Agency on its analysis and proposed alternatives. And we are receiving a positive response to our efforts—EPA, in a letter on our draft environmental impact statement (EIS) for alfalfa, indicated no objection to APHIS' determination to grant non-regulated status and rated the draft EIS as "Lack of Objections," which indicates EPA had no concerns regarding APHIS' determination.

Herbicide Resistance – Issues, Challenges, and USDA's Role

At USDA, we recognize that herbicide resistant weeds pose an important challenge. You've asked me to speak to the Subcommittee today about how USDA approaches this issue in relation to the regulation of GE crops. I'd like to lay out this relationship, and then discuss how we're looking at herbicide resistance more broadly within USDA.

First, the development of herbicide resistance among weeds is a natural and evolutionary process. Many weed species evolved resistance to a wide variety of herbicides long before the advent of GE crops, resulting from the common use of herbicides in agriculture for decades. This is not a new concern for agriculture and is not exclusively associated with GE crops. Any time an herbicide or any other weed control tactic is used continually—whether with GE or non-GE crops—it is going to put pressure on weeds to develop resistance. USDA understands that growers are being challenged by these issues, and that they're looking for guidance and assistance. And we want to help, which is why we have a number of initiatives underway that I'll mention shortly.

Second, we are committed to meeting our obligations under NEPA and are committed to performing the appropriate NEPA environmental reviews and seeking the views of the public on these issues. However, while the consideration of herbicide resistance in weeds under the NEPA process informs our decision making, USDA decisions on the regulation of GE crops are ultimately based on plant pest risk, consistent with our authority under the Plant Protection Act (PPA). Relatedly, I would like to clarify, in response to two questions the Subcommittee has asked me to discuss, that, because our regulatory decisions are ultimately based on plant pest risk under the PPA, 1) Herbicide resistance in weeds is not being addressed in APHIS' proposed revisions to its biotechnology regulations and, 2) APHIS has not considered alternatives to full deregulation of a GE product in order to address herbicide resistant weeds, because there must be a plant pest risk to deny a full deregulation, and herbicide resistance does not constitute a plant pest risk.

Third, as policy considerations are made, we must be cognizant not to lose the many benefits of GE crops, such as overall reduced pesticide use, increased use by farmers of less damaging pesticides, and decreased soil erosion due to increased use of no-till farming. According to the National Research Council's 2010 report, *The Impact of Genetically Engineered Crops on Farm Sustainability in the United* States:

> *For GE farmers, the general increase in yield, reduction in some input costs, improvement in pest control, increase in personal safety, and time management benefits have generally outweighed the additional costs of seed. The use of [herbicide resistant] crops...has generally improved weed control...improved farmers' incomes by saving time thus facilitating more off-farm work or providing more management time on the farm.*

Additionally, advances in biotechnology have provided farmers with safe, environmentally friendly tools for feeding our country and the world. If we limit the use of herbicide tolerant crops, farmers will likely have to return to older, often costly, and less environmentally-friendly weed control methods. At the same time, we are mindful of the economic impact on farmers caused by herbicide resistant weeds. This is why, as I'll discuss next, we are investing in research on solutions to this growing issue.

Multiple USDA agencies are engaged in addressing herbicide resistant weeds through research, education, and partnerships with other Departments and outside groups. USDA's National Institute of Food and Agriculture (NIFA) supports research, education, and extension programs

in the Land-Grant University System and other partner organizations. In 2009, NIFA relaunched its competitive grants program as the Agriculture and Food Research Initiative (AFRI), and offered $4.6 million in the Biology of Weedy Invasive Species in Agroecosystems program area. In 2010, NIFA restructured AFRI to be more responsive to important national issues. Of the five societal challenge areas scientists receiving grants will work under, weed science is included in both Climate Change and Global Food Security, and can also be addressed under the Sustainable Bioenergy Production focus area.

Providing the connection between the results of scientific studies and their actual application on farms is key to addressing herbicide resistance among crops derived through conventional methods and biotechnology. This is why NIFA supports Extension outreach programs to actively disseminate research findings to agricultural producers who could benefit from new knowledge about the management of herbicide resistance. For example, Extension weed scientists along with Extension integrated pest management and pesticide safety education specialists regularly discuss the issue of herbicide resistance management during training sessions and field day activities with growers. NIFA is also supporting the development of a web-based training system, called IPM^3, which offers training in a wide variety of topics related to integrated pest management (IPM). IPM^3 offers a weed module that includes herbicide resistance issues and management strategies. Anyone who completes this training will have a good understanding of weed biology and science-based management strategies that will reduce the potential for the development of herbicide resistance.

USDA's principal in-house research agency, the Agricultural Research Service (ARS) is funding nearly $4.4 million in herbicide resistant weed research in FY 2010, which is part of ARS' $36 million research effort this year on all weed science issues. I will briefly mention just two of the research projects underway. First, scientists at ARS' Crop Production Systems Research Unit in Stoneville, MS, are conducting studies on the development and management of herbicide-resistant weeds. The studies will examine the mode-of-action of herbicides and mechanisms of resistance, the reproduction and spread of weeds, and the development of integrated weed management techniques, in order to develop strategies for sustainable management of existing herbicide-resistant weed populations and to prevent future incursions. Second, scientists at the Natural Products Utilization Research Unit in University, MS, are conducting studies to discover natural product-based chemistries in order to provide new tools to control weeds resistant to current herbicides.

Additionally, APHIS has partnered with the Weed Science Society of America (WSSA) to identify methods being used to manage the spread and development of herbicide resistance in weeds, assess their effectiveness and degree of adoption, understand the reason for adoption or non-acceptance, and identify what can be done to increase the use of integrated resistance management programs. WSSA also recently completed a project for APHIS, in coordination with EPA, to understand the extent of herbicide resistance in managed ecosystems.

While these are just a few examples of USDA's efforts to address herbicide resistant weeds, we are committed to continuing to work with our partners to identify potential solutions and alternative techniques and technologies to address this important issue. This is going to require a coordinated effort by everyone involved—the government, researchers, the agricultural

community, technology and crop protection companies, and public interest groups, to name a few.

Moving Forward with Addressing Biotechnology in USDA

Biotechnology is a critical tool in addressing important global issues, including food security, biomass production, sustainability, and climate change. USDA continues to be committed to a strong, science-based regulatory system that ensures that the products of biotechnology are safe for agriculture and the environment, food, and feed. At the same time, we continue to see the direct results that the benefits that biotechnology can offer.

With that in mind, we are working to maintain rigorous polices and regulations that ensure product safety. We are also working to ensure that our policies and regulations keep pace with new technologies as they develop. And we want to develop and implement policies that promote the coexistence of genetically engineered, conventional, and organic crops, to help meet the agricultural challenges and consumer needs of the 21st century. Products produced through biotechnology will continue to be an important part of U.S. agriculture, and USDA has a complex and critical role in protecting consumers, the environment, and the farm economy while also contributing to global food needs.

Herbicide resistant weed development is not wholly a biotechnology issue, and we at USDA are looking at it in a much broader context to determine how everyone involved with this issue can evolve to address this challenge. Our agricultural producers are a resilient group, and we are confident that together, we can find sound solutions that make sense.

Thank you for the opportunity to testify today. I'd be happy to answer any questions.

Mr. KUCINICH. Thank you. Mr. Jones.

STATEMENT OF JIM JONES

Mr. JONES. Good afternoon, Chairman Kucinich, Chairman Towns. I am pleased to appear before you today to discuss the Environmental Protection Agency's regulation of transgenic B.t. crops, as well as EPA's involvement with the U.S. Department of Agriculture and their assessments of the environmental impact of herbicide-tolerant crops and herbicide-resistant weeds.

Under the coordinated framework for the regulation of biotechnology, EPA regulates products produced through biotechnology that are intended to have a pesticidal effect under its authorities under the Federal Insecticide, Fungicide and Rodenticide Act, and the Federal, Food, Drug and Cosmetic Act.

EPA first registered a transgenic B.t. crop in 1995. Over the past 15 years, B.t. crops have substantially reduced the need for growers to apply older, more risky conventional chemical pesticides to corn and cotton crops. Because sprayable B.t. formulations are naturally derived organic pesticides, they are very important to organic farmers. Given the importance of this technology to organic agricultural as well as the favorable environmental profile of B.t. as a pesticide, EPA has, from the very beginning of its regulation of transgenic B.t. crops, required registrants to market these products with specific mandatory insect-resistant management requirements.

EPA would consider the development of insect resistance to B.t. toxins to constitute and adverse effect on the environment. These IRM requirements have evolved as the science has evolved, and we have altered and tailored the IRM requirements to match the latest and most relevant scientific data and information.

The USDA regulates genetically engineered herbicide-tolerant crops, while EPA regulates the herbicides used on these crops. In order to coordinate our reviews in 2001, the agencies developed a Memorandum of Understanding that outlined the Agency's respective roles. In 2007, responding to increases in reported cases of resistance, EPA and USDA held discussions on the extent to which herbicide-resistant weeds were occurring in the herbicide-tolerant crops. As a result of these discussions, the EPA and USDA initiated a project with the Weed Science Society of America to develop a comprehensive manuscript to better understand the scope of herbicide resistance in genetically engineered, and non genetically engineered cropping systems. The report is due later this year.

As glyphosate-resistant weeds have become more widespread in herbicide-tolerant crops, technology providers and users have become more open to efforts to address herbicide-resistant weeds. The support for resistance management from technology providers and users has spurred the development of strategies to prevent or manage herbicide-resistant weeds in herbicide-tolerant crops.

EPA and USDA are working with researchers and professional societies to expand resistance management education and promote research aimed at increasing the understanding of the best practices and strategies for preventing and managing herbicide-tolerant weeds. EPA is also working with pesticide registrants encouraging them to include mechanism of action information on herbicide la-

bels. This information is critical to the implementation of resistance management plans, which typically involve rotation of two herbicides with different mechanism of action as a proven strategy for preventing or delaying development of resistance.

Recently, EPA and USDA have reinvigorated our efforts in this area to promote resistance management in herbicide-tolerant crops and preserve this valuable technology. We look forward to working with this committee, our fellow agencies, our stakeholders in the public, to ensure an environmentally and economically healthy country for all Americans. Thank you, and I'd be pleased to answer any questions.

[The prepared statement of Mr. Jones follows:]

TESTIMONY OF

JIM JONES
DEPUTY ASSISTANT ADMINISTRATOR FOR
CHEMICAL SAFETY AND POLLUTION PREVENTION
U.S. ENVIRONMENTAL PROTECTION AGENCY

BEFORE THE
DOMESTIC POLICY SUBCOMMITTEE
OVERSIGHT AND GOVERNMENT REFORM COMMITTEE
UNITED STATES HOUSE OF REPRESENTATIVES

September 30, 2010

Introduction

Good afternoon Chairman Kucinich, Ranking Member Jordan, and Members of the Committee. I am pleased to appear before you today to discuss the Environmental Protection Agency's (EPA) regulation of transgenic *Bacillus thuringiensis* (B.t.) crops. I welcome the opportunity to participate on this panel and explain the steps that EPA has taken to forestall the development of insect resistance to these important crops. Further, I look forward to discussing EPA's involvement with the U.S. Department of Agriculture in their assessments of the environmental impacts of herbicide tolerant crops and herbicide resistant weeds. EPA provided technical expertise to USDA to assist in the development of herbicide stewardship plans. More recently, as USDA has engaged in analysis of these crops under the National Environmental Policy Act (NEPA), EPA is expanding its support to USDA in its environmental analyses.

The Coordinated Framework and NEPA

EPA and USDA share responsibility, along with FDA, for regulating agricultural biotechnology. The Coordinated Framework for the Regulation of Biotechnology, released in 1986, describes each agency's role and sets forth a comprehensive scheme for federal regulation of biotechnology. The basic framework was that the products of biotechnology were to be regulated under existing statutory authorities and in a manner similar to products produced by means other than biotechnology. Thus, EPA regulates products produced through biotechnology that are intended to have a pesticidal effect under its authority under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the sections of the Federal Food, Drug, and Cosmetic Act (FFDCA) applicable to residues of pesticides in food and feed.

Under the Plant Protection Act, USDA's Animal and Plant Health Inspection Service (APHIS) regulates the introduction of organisms altered or produced through genetic engineering that are plant pests, may be plant pests, or may be related to plant pests. APHIS has procedures whereby a person may petition APHIS for a determination that an otherwise regulated article does not pose a plant risk and should not be regulated. USDA recently completed a NEPA analysis of glyphosate-tolerant alfalfa and EPA provided comments on the sections of that Environmental Impact Statement that discuss development of resistance. EPA is also providing support to USDA on an EIS for glyphosate-tolerant sugarbeet that is under development. EPA stands ready to provide whatever additional assistance may be needed in the future.

EPA's Regulation of B.t. Plant Incorporated Protectants

EPA first registered a transgenic B.t. crop product in 1995. Over the past fifteen years, B.t. crops have substantially reduced the need for growers to apply older, more risky conventional chemical pesticides to corn and cotton crops. As B.t. crops now comprise over 60% of planted corn acreage, and over 90% of planted cotton acreage, the decreasing usage of more risky pesticides has significantly reduced health risks to farm workers. Also as a condition of B.t. corn and cotton registrations, EPA required that registrants conduct field surveys to assess biodiversity in B.t. crop fields compared to non-B.t. crop fields.

Those data, along with independent assessments published in the scientific literature, have conclusively demonstrated that there is significantly greater insect biodiversity in B.t. crop fields compared to fields treated with conventional pesticides. Because sprayable B.t. formulations are naturally derived organic pesticides, they are very important to organic farmers and organic agricultural production in general. Given the importance of this technology to organic agriculture, EPA has, from the very beginning of its regulation of transgenic B.t. crops, addressed the potential issue of resistance by requiring that B.t. crop registrants market these products with specific mandatory insect resistance management (IRM) requirements. These requirements have evolved as the science has evolved, and we have altered and tailored the IRM requirements to match the latest and most relevant scientific data and information.

EPA's development of a regulatory scheme for plant incorporated protectants (PIPs) began in the 1980s. EPA held public meetings with the Agency's Biotechnology Safety Advisory Committee (BSAC), the FIFRA Scientific Advisory Panel (SAP), the Office of Pesticide Programs Pesticide Program Dialogue Committee (PPDC), and numerous public meetings and workshops with interested stakeholders. Through this long process of stakeholder consultation and external scientific peer review, EPA developed a rigorous and robust regulatory approach to PIPs that was based on the most up to date science. From the very beginning, it was clear that developing methodologies and approaches to forestall the development of insect resistance should be a major focus of the Agency in its regulation of B.t. crops. EPA has regularly met with the SAP on IRM issues, and, as the IRM requirements have evolved on the basis of new data and information, the SAP has provided key input into these regulatory developments.

To address the potential of insect resistance to B.t. proteins, EPA has imposed IRM requirements on registered B.t. PIPs. EPA would consider the development of insects resistant to B.t. toxins as a result of unmitigated exposure to PIPs to constitute an adverse effect on the environment. EPA's strategy to address insect resistance to B.t. is two fold: (1) mitigate any significant potential for pest resistance development in the field by instituting IRM plans; and (2) continually investigate and understand better the mechanisms behind pest resistance. Initially, IRM plans incorporating "refuges" (portions of the crop that did not produce and were not treated with B.t.) were determined on a case by case basis using data submitted with each application. As a consequence,

IRM requirements varied from product to product. In 2000, based upon input from the SAP, and working with the National Corn Growers Association and other groups, EPA imposed across the board IRM requirements of a 20 percent refuge for B.t. corn and a 5 percent refuge for B.t. cotton.

The baseline 20 percent refuge for corn and 5 percent refuge for cotton held for a number of years until more complex products were developed and supporting scientific data indicated that it was appropriate to alter these requirements. For B.t. cotton, registrants developed "pyramided" products that contained more than one B.t. protein efficacious against a specific pest ("stacked" products contain B.t. toxins efficacious against more than one pest). By targeting the pest with independently acting toxins, the likelihood of resistance developing to either toxin was substantially decreased, and it became possible for EPA to decrease the percentage of refuge crop required for a pyramided crop.

Also, registrants developed data demonstrating that in many cotton producing areas, non-cotton plants that are food sources for cotton pests often surround, or are close by cotton fields. In effect, in these areas, the cotton fields are surrounded by "natural" refuges.

These large alternative sources of habitat for cotton pests, combined with pyramided B.t. cotton products, precluded the need for growers to plant refuges for those products. Thus, for pyramided B.t cotton products planted from Maryland to Kansas,

there are no refuge requirements. Those same products planted outside of these areas maintain the requirement for planted refuges. Similarly for B.t. corn, new products are being developed that support refuge requirements different from the baseline 20 percent corn refuge. Registrants have developed pyramided corn products that require refuges of 5 percent or 10 percent non-B.t. corn seed. Also, registrants are developing products that incorporate refuge seed in the same seed bag as the B.t. corn seed, such that when planted, an in field refuge is automatically put in place. To date, there have been no confirmed instances of B.t. resistant pests appearing in the field in the Continental United States. We will maintain our diligent approach to forestalling potential resistance to B.t. crops.

In addition to requiring that registrants require purchasers of their products to plant crop refuges, EPA mandates that registrants monitor for resistant insects emerging during the growing season as an important early warning sign of resistance developing in the field and a check as to whether IRM strategies are working. Grower participation, e.g., reports of unexpected damage, is a critical component of such monitoring. Resistance monitoring is also important because it provides validation of biological parameters used in models. In 2000, the SAP concluded that resistance monitoring programs should be peer reviewed and used to assess the success of IRM plans. EPA's Office of Research and Development, National Risk Management Research Laboratory and Office of Pesticide Programs held a small expert group workshop in July, 2001, that provided guidance on insect resistance monitoring plan design and detection techniques for B.t. corn.

EPA and USDA Cooperation on Herbicide Resistance Concerns

USDA regulates genetically engineered herbicide-tolerant crops, while EPA regulates the herbicides used on these crops. Recognizing the need for EPA and USDA/APHIS to coordinate their reviews, the agencies developed a Memorandum of Understanding (MOU) in 2001 outlining a process for improved communication and information-sharing to facilitate better coordination of regulatory activities between the two agencies. Under the MOU, USDA was to request that each petition for "deregulated" status include a voluntary stewardship plan for the management of herbicide resistance, and then consult with EPA as to the viability of the stewardship plan during its environmental assessment.

To implement relevant portions of the MOU, USDA and EPA developed a draft document to assist applicants in the preparation of voluntary resistance management stewardship plans to be submitted with petitions for nonregulated status of herbicide-tolerant (HT) crops, and with applications to EPA to register herbicides intended to be used on HT crops. Initial efforts by EPA and USDA to implement the provisions of the MOU were met, however, with resistance from both users, pesticide registrants, and the technology providers. At that time, the development of resistance in weeds as a result of the use of HT crops was not widely documented in the scientific literature, nor was it viewed as a significant problem by these stakeholders, who considered the economic costs of developing and implementing a stewardship program unnecessary.

In 2007, responding to increases in reported cases of resistance, EPA and USDA held discussions on the extent to which herbicide resistant weeds were occurring in herbicide tolerant crops. As a result of these discussions, EPA and USDA initiated a project with the Weed Science Society of America (WSSA) to develop a comprehensive manuscript to better understand the scope of herbicide resistance in genetically engineered and nongenetically engineered cropping systems. This report is due later this year.

As glyphosate resistant weeds have become more widespread in HT crops, technology providers and users have become less resistant to efforts to address herbicide resistant weeds. The support for resistance management from technology providers and users has spurred the development of strategies to prevent or manage herbicide resistant weeds in HT crops. More recently, EPA has provided comments on the section of USDA's EIS that discuss the development of resistance as a result of the deregulation of glyphosate-tolerant alfalfa.

EPA and USDA are working with researchers and professional societies, including the Weed Science Society of America (WSSA), to expand resistance management education and promote research aimed at increasing understanding of the best practices and strategies for preventing and managing HT weeds in HT crops. EPA is also working with pesticide registrants, encouraging them to include mechanism of action information on herbicide labels. This information is critical to the implementation of resistance management plans, which typically involve rotation to herbicides with a

different mechanism of action as a proven strategy for preventing or delaying development of resistance.

There has been much attention given to the best way to delay or prevent the development of pesticide resistance to pests in general, beyond resistance in weeds in glyphosate-tolerant crops. Professional scientific societies, e.g., the Weed Science Society of America, the Entomological Society and the American Phytopathology Society, as well as Resistance Action Committees (composed of technical staff from pesticide producers) have been involved in identifying ways to accomplish this goal. EPA has been in discussion with each of these groups to obtain their input on how to incorporate guidance on resistance management on pesticide labels.

Additionally, EPA has been collaborating with its NAFTA partners (The Pest Management Regulatory Authority (PMRA) of Canada and Cicoplafest of Mexico) to develop harmonized approaches to resistance management language on pesticide labels EPA has and continues to encourage pesticide registrants to include mechanism of action information on pesticide labels to better inform growers and other pesticide users of one proven strategy for preventing or delaying development of resistance.

In summary, the early efforts by EPA and USDA to implement the resistance management provisions of the 2001 MOU were hindered by the lack of interest and support from the technology providers and user community. Recently, however, with the support of these sectors, EPA and USDA have reinvigorated their efforts in this area,

working collaboratively to promote resistance management in HT crops and preserve this valuable technology.

We look forward to continuing our work with this Committee, our fellow agencies, our stakeholders, and the public to ensure an environmentally and economically healthier country for all Americans.

Mr. KUCINICH. Thank you very much. I would like to begin the first round of questions with Ms. Wright. As you know, the USDA, since they began deregulating Roundup-Ready Corn, Soy And cotton, among other genetically engineered herbicide-resistant crops in the late 1990's, weed scientists estimate that there are up to 11 million acres of American farmland, and a dozen species of weeds that have evolved to be resistant to Roundup herbicide. The result for farmers has been greatly increased cost of weed management, and a probable loss of Roundup as an efficacious weed control chemical in large parts of the country. Is it the position of the USDA that it could not regulate genetically engineered herbicide-resistant crops in order to prevent this spread of herbicide-resistant weeds?

Ms. WRIGHT. Mr. Chairman, USDA recognizes the development of herbicide-resistant weeds across the board.

Mr. KUCINICH. What does that mean?

Ms. WRIGHT. It means that we recognize it as probably the No. 1 issue for farmers and ranchers whether they are raising crops using biotechnology, or organic, or conventional seed. I think we have a number of ways that we're looking at this through our active and dedicated research programs that are looking at critical national priorities like the sustainable production of bioenergy climate change, global food security. We continue to see this issue as critical to farmers bottom lines.

And right now, we have confidence in a science-based process that regulates in and around our plant protection authorities, our statutory commitments are to that act.

Mr. KUCINICH. Well, you know, that's very interesting, but the question that I asked is, is it your position that the USDA could not regulate genetically engineered herbicide-resistant crops in order to prevent the spread of herbicide-resistant weeds?

Ms. WRIGHT. That's correct. Our statutory authority allows us to make regulatory decisions based on plant pest risk.

Mr. KUCINICH. Tell me more about that.

Ms. WRIGHT. Well, what I can tell you is that the plant pest risk is determined by—well, I'm going to let——

Mr. KUCINICH. Let me go to Mr. Jones a minute. Mr. Jones, the EPA has taken a different position. EPA believed that it could regulate one genetically engineered plant variety in particular, those containing the B.t. or the Bacillus thuringiensis gene in order to prevent the development of pest resistance to B.t.; is that correct?

Mr. JONES. That's correct. We're operating under a different statute, in this case, FIFRA.

Mr. KUCINICH. Mr. Jones, I understand the EPA's been regulating B.t. crops to prevent pest resistance for about 15 years. Is there a problem with B.t. resistance in this country comparable to the problem of Roundup resistance in weeds?

Mr. JONES. There is not.

Mr. KUCINICH. Pardon?

Mr. JONES. No, there is not.

Mr. KUCINICH. Are there 11 million acres of B.t. resistant farmland right now?

Mr. JONES. We're not aware of resistance yet——

Mr. KUCINICH. How many acres of American farmland has been infested with B.t. resistant pests?

Mr. JONES. We're not aware of any. It doesn't mean there isn't some.

Mr. KUCINICH. Well, is B.t. still an efficacious pesticide in the United States?

Mr. JONES. It is.

Mr. KUCINICH. Does it concern EPA to learn that weed resistance to Roundup is now widely prevalent?

Mr. JONES. Yes.

Mr. KUCINICH. If so, why?

Mr. JONES. Glyphosate to Roundup is—has a very favorable, as you mentioned in your opening remarks, environmental profile. And so it's a compound that we think it's in the interests of the environment to have a long commercial life.

Mr. KUCINICH. So your saying that it's because the glyphosate is relatively benign?

Mr. JONES. It has a very favorable environmental profile.

Mr. KUCINICH. Ms. Wright, 11 million acres of infested farmland, $1 billion in added weed control costs to farmers. The loss of efficacy for a relatively benign pesticide in many places, these are some of the consequences of the USDA's position that it could not regulate Roundup Ready crops to prevent the evolution of resistant weeds.

Now, Ms. Wright, you say in your written testimony, "There must be a plant pest risk to deny a full deregulation. An herbicide resistance does not constitute a plant pest risk." Now I'm questioning your legal interpretation as to whether it's well-founded. Your position is that the sum total of the USDA's authority derives from section 411 of the Plant Protection Act which gives the Secretary authority to prevent the introduction of plant pests.

But that is not the sum total. The very next section of the act, section 412, covers your authority to prevent the spread of, "Noxious weeds." Section 412 "gives the Secretary authority to prohibit or restrict . . . the movement . . . of any plant . . . if the Secretary determines that the prohibition or restriction is necessary to prevent . . . the dissemination of a . . . noxious weed within the United States," from the statute. Now "noxious weeds" are defined by the statute at 7 U.S.C. section 7702 as, "Any plant or plant product that can directly or indirectly injure or cause damage to crops or . . . other interests of agriculture . . . or the environment."

Ms. Wright, a plain reading of section 412 gives the Secretary the broad authority to restrict the use of Roundup-resistant crops if sound science determines that those restrictions are necessary to prevent the spread of Roundup-resistant noxious weeds. How can you come to Congress and insist that effectively that section 412 doesn't even exist?

Ms. WRIGHT. Well, first let me say that this USDA is very committed to looking at all of our programs and policies, and ensuring that they are there for all forms of agriculture——

Mr. KUCINICH. I know you're not—this is your first time before a committee.

Ms. WRIGHT. It is.

Mr. KUCINICH. And I do appreciate your being here. I asked you a question, and I would like an answer. That was not responsive.

Ms. WRIGHT. We interpret our existing authorities as those focused on plant pest risk. Back in March 2009, we issued a set of updates to our rules and regulations that expanded our authorities into the Noxious Weed Act. We're now looking at 66,000 comments on those rule updates. This is a new administration, we will be taking a close look at the full range of comments that came in and be looking very carefully at where our authorities are.

Mr. KUCINICH. Are you familiar with section 412 of the act?

Ms. WRIGHT. No, sir.

Mr. KUCINICH. You're really not? Before the end of this hearing, I would like staff to have a copy made of section 412 of the act and provide it to the witness, because if the regulatory agency is not fully familiar with the extent of its authority, it may be one of the difficulties we're having here.

Ms. WRIGHT. I think the Agency is probably very familiar, but I personally am not, and I'm sorry.

Mr. KUCINICH. Well, I can understand that it is a new administration, and that you're new, and you do have a very good reputation where you come from. But I think it's important that you become familiarized with the act and with the sections that I articulate, particularly section 412, which actually does change the role of your agency and your office to effectively regulate herbicide-resistant weeds. If you—I'll take you at your word that you're not familiar with it.

But what I glean from that, since you are not familiar with it, you can't point to any provision of the Plant Protection Act that would deny the USDA the ability to use the authority of the section to prevent the spread of Roundup-resistant weeds.

I think it's clear from your testimony that the USDA's position is not too much a legal judgment as is a statement of policy. And that it's been the policy of the USDA not to use the authority that it does have under section 412, it's just very clear. I just want to make this statement to you as the chairman of this oversight subcommittee that a plain reading of section 412 makes it obvious that if the Agency wants to become involved in the enforcement of herbicide-resistant weeds, that it could do it, that you do have the statutory authority to do it, and that it's a policy question.

Now you may not be the person who makes the final call on that, but somebody all the way up to—the ladder at Agriculture is making that call, and this subcommittee's determined to see the statute enforced.

Now, Ms. Wright I know that the Department understands at this point, that the problem of superweeds is a crisis. What I don't understand, and what defies comprehension is this: That the Department does have the legal ability to help farmers deal with the crisis, and to prevent it from worsening, and that the USDA has not made a policy, a decision to use this authority or has made a policy decision not to use it. Do you have anything further that you can tell this subcommittee? You will read the statute?

Ms. WRIGHT. Thank you. Yes, I promise to fully read the statute and I would like to say—and thank you for the opportunity to address this problem and to address the entire issue of coexistence.

We're going to have to have a full slate of partners at the table looking at this, including Congress, as well as technical service providers, other Federal agencies, regulated entities and public interest groups. And together, I think, we will be able to solve this problem, including growers, it's not one that—as well as the markets, it's not one that exclusively rests on our shoulders.

Mr. KUCINICH. Ms. Wright, I want to draw attention to the Department's view that it currently has authority to regulate future planting of GE crops through administrative action. The Department outlined three such actions in a court filing from July of this year. I move to insert into the record the fourth declaration of the APHIS administrator Cindy Smith.

[The information referred to follows:]

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA
SAN FRANCISCO DIVISION

CENTER FOR FOOD SAFETY, *et al.*, Plaintiffs, vs. TOM VILSACK, *et al.*, Defendants, and MONSANTO COMPANY; SYNGENTA SEEDS, INC.; AMERICAN SUGARBEET GROWERS ASS'N, *et al*,: BETA SEED, INC.; and SESVANDERHAVE USA, INC., Defendant-Intervenors.	Case No.: 3:08-cv-00484-JSW

FOURTH DECLARATION OF CINDY SMITH

I, Cindy Smith, do hereby declare as follows:

1. I make the following statements based on my personal knowledge and experience as well as upon facts made known to me in my capacity as the Administrator of the Animal and Plant Health Inspection Service (APHIS), United States Department of Agriculture (USDA).

2. I previously provided declarations on February 12, May 7, and June 18, 2010.

3. I am providing this declaration to respond to the Court's June 24, 2010 Order requiring APHIS to address the Supreme Court's statement in Monsanto Co. v. Geertson Seed

Farms, __ U.S. __, 2010 WL 2471057, at *15 (2010), regarding the effect of an immediate vacatur of APHIS' determination of nonregulated status.

4. If the determination of nonregulated status on Roundup Ready sugar beets (RRSB) is vacated and the vacatur would go into effect immediately, RRSB would again be a regulated article under 7 C.F.R. Part 340 and the Plant Protection Act (PPA). As a regulated article, RRSB could neither be planted nor moved interstate without approval from APHIS. However, a new deregulation decision, whether in whole or in part, is not the only means for APHIS to approve future planting (release into the environment) and/or interstate movement of the regulated RRSB.

5. There are several administrative actions under the authority of the PPA and/or Part 340 that APHIS could take to allow the planting and/or interstate movement of regulated RRSB.

a. First, APHIS has the authority to allow the planting of RRSB as a regulated article under permit. Permitting is the regulatory scheme under Part 340. Permits are issued after appropriate NEPA analysis. The type of NEPA documentation needed will affect the timing of the issuance of the permit.

b. Second, APHIS may either revise the Part 340 regulations or issue a new rule, after notice and comment, in order to allow the APHIS Administrator to use her discretion to allow the planting of RRSB under a revised or new regulatory scheme pursuant to PPA statutory authority. (7 U.S.C. §§ 7711, 7712, 7714, and 7754). If APHIS revises Part 340 or issues a new rule to allow the Administrator the discretion to impose a different regulatory scheme than is currently employed under Part 340, such as the use of general permits, administrative orders or other PPA authority, APHIS would conduct the appropriate NEPA analysis prior to taking any regulatory action provided for by the rule change.

c. Third, the PPA provides APHIS with the authority to issue orders as the Secretary considers necessary to carry out the PPA. (7 U.S.C. § 7754). Prior to the issuance of such an order, APHIS would conduct the appropriate NEPA analysis and prepare the appropriate documentation, which will affect the timing of such an order.

6. The PPA prohibits the importation, entry, export, or movement (including release into the environment) of a plant pest unless the movement is authorized under a general or specific permit and is in accordance with such regulations as the Secretary may issue to prevent the introduction into or dissemination within the United States of a plant pest. 7 U.S.C. § 7711(a). APHIS currently allows the movement of genetically engineered regulated articles under a permitting scheme, using specific permits and notifications. Notification is a form of permit. APHIS reviewed its permitting process under Part 340 and in 1995 (60 Federal Register 6000) determined that permits and notifications complied with and satisfied the categorical exclusion requirements set forth in APHIS's NEPA implementing regulations. (7 C.F.R. §372.5(c)(3)(ii)). Prior to the deregulation of RRSB in 2005, RRSB was a regulated article which was allowed to be planted and grown under notification.

7. APHIS has overseen numerous field trials under Part 340. At least 142 of the authorizations since 2006 were for crops ranging from just over 1000 acres to 20,000 acres. The field trials were overseen by APHIS through inspections and/or third party inspections and auditing. APHIS ensures that every permit is inspected by APHIS staff or by a qualified independent third party inspector.

8. As I declared both in my second and third declarations, I respectfully proposed that the Court order a remand without vacatur until May 31, 2012, and impose the specific interim measures that I described in detail in paragraphs 44-45 of my second declaration pending

completion of the RRSB Environmental Impact Statement (EIS). (Second Smith Decl. at ¶¶ 44-45, Third Smith Decl. at ¶ 5). Such court-imposed measures would provide certainty for farmers of the RRSB seed and root crops that APHIS action, which is subject to challenge, cannot provide. In the alternative, if the Court is inclined to immediately vacate and remand APHIS's determination of non-regulated status of RRSB, I respectfully requested that the Court stay its vacatur of APHIS's Determination of Non-Regulated Status for RRSB until March 1, 2011, to allow APHIS adequate time to establish appropriate interim regulatory measures to deal with all regulated RRSB until completion of the RRSB EIS. (Third Smith Decl. at ¶ 6). If the Court is inclined to vacate APHIS's determination and remand but is not inclined to stay the vacatur until March 1, 2011, I respectfully requested that the Court, at the very least, stay the vacatur with respect to all RRSB in the United States currently planted as of the date of the Court's order. Such an order would prevent significant harm to the thousands of farmers that have currently planted RRSB in the United States and would prevent significant harm and disruption to sugar beet sugar supplies and prices. (Id. at ¶ 8).

9. If there is an immediate vacatur and remand, the following RRSB activities would either be taking place on the Court's August 13, 2010 hearing date or be imminent: (1) the harvest and interstate movement of the 2009-2010 seed crop from the fields to seed processing plants which is expected to occur between July and October 2010; (2) the interstate movement of the 2009-2010 seed crop harvested between July and October 2010, from processing plants along the sales chain (i.e. to distributors and individual growers), which is expected to take place from November 2010 to March 2011; (3) the planting of the 2010-2011 seed crop which is expected to take place as early as July 2010, and is likely to be completed by the end of September 2010; and

(4) the harvest and interstate movement of the 2010 root crop from field to sugar processing plants which is expected to take place from September 2010 to December 2010.

10. If the vacatur does not apply to any RRSB crop that has been planted as of the date of a vacatur, only new plantings after that date and other releases into the environment (e.g. flowering of the seed crop) would require the agency's approval. The planting of the 2010-2011 seed crop is the only activity that is imminent and would require immediate regulatory action by APHIS.

11. If permits for new plantings of the 2010-2011 RRSB seed crop were to be requested by Intervenors seed companies after vacatur, APHIS has the authority to issue permits solely for the planting of RRSB seed crop under a categorical exclusion as currently provided for under Part 340, provided that APHIS determines that none of the exceptions to the categorical exclusion applies. However, such permits for the planting of the RRSB seed crop would still take some time, possibly up to a month before they could be issued. The time needed to issue such permits could likely prevent certain seed growers from any further planting of the RRSB seed crop after vacatur, depending on factors such as the date by which they must complete their seed planting. It would be expected that any permits APHIS may issue in time for the planting of the 2010-2011 RRSB seed crop could allow planting but would not allow flowering, which would not be expected to occur until approximately May 2011. To address the flowering stage of the RRSB seed crop, APHIS may, after preparing an EA, issue a new permit or an amended permit under Part 340 or under other regulatory mechanisms (as described in paragraph 5 above). APHIS has considerable experience with the issuance of permits that do not allow flowering and with the issuance of permits that only allow flowering under strict conditions. An EA for new or

amended permits that would allow flowering of the RRSB seed crop would be expected to be completed by March 1, 2011.

APHIS could also use its authority under the PPA to issue a federal order to address imminent RRSB activity after the appropriate NEPA analysis and documentation is prepared. APHIS is currently considering how such authority to issue orders might be used.

12. In addition to the immediate activities related to regulating RRSB (both seed and root crops) in the United States as described above, the following are additional planting or interstate movement RRSB activities that would occur prior to the time when APHIS completes its RRSB EIS and that would require APHIS approval, if requests for such production actions were made: (1) the planting of the 2011 root crop which is expected to take place between April and July 2011 and the interstate movement of this 2011 harvested root crop, which is expected between September and December 2011; (2) the harvest and interstate movement of the 2010-2011 seed crop, planted after vacatur, from the fields to the processing plants, which is expected to occur between July and October 2011; (3) the interstate movement of 2010-2011 seed crop, planted after vacatur, from processing plants along the sales chain (i.e., to distributors and individual growers), which is expected to take place from November 2011 to March 2012; (4) the planting of the 2011-2012 seed crop which is expected to occur between July and September 2011; and (5) the planting of the 2012 root crop which is expected to occur between April and July 2012. With regard to these production activities, if requests for such production actions were made, APHIS could use any of the authorities as described in paragraph five above to allow the activities under PPA regulation with the appropriate NEPA analysis and documentation.

13. APHIS has the authority pursuant to 7 C.F.R. § 340.6 to approve a petition for determination of nonregulated status in whole or in part. If APHIS were to receive a new

petition or a supplement or amendment to a previous petition for a determination of nonregulated status of RRSB, APHIS could consider granting that petition in whole or in part. Depending upon the specific petition and its complexity, if APHIS were to approve such a petition, APHIS anticipates that it could take at least until March 1, 2011, to complete the appropriate NEPA analysis and documentation and the appropriate plant pest risk assessment.

I declare under penalty of perjury that the foregoing is true and correct.

Executed this 15th day of July, 2010, in Washington, D.C

Cindy J. Smith, APHIS Administrator

Mr. KUCINICH. My question, Ms. Wright, is this: Is it also the Department's view that it could, by means of any of those administrative actions, place requirements on a permitted planning of GE herbicide-tolerant crops to prevent the proliferation of herbicide-resistant weeds.

Ms. WRIGHT. In both the case of GE alfalfa as well as GE sugar beets there are currently formal petitions before the agency for us to look at ways to partially deregulate these.

Mr. KUCINICH. So that's a yes?

Ms. WRIGHT. We're in the process of looking at that.

Mr. KUCINICH. So that's a yes?

Ms. WRIGHT. So the industry has come to us and asked us to look at that options.

Mr. KUCINICH. So is this consistent with the testimony that has been given in court?

Ms. WRIGHT. Yes.

Mr. KUCINICH. You found expansive authority to devise three administrative actions allowing to you approve large scale planting under a permit system. What is the basis? Do you have——

Ms. WRIGHT. No, sir. The industry came to us and asked us to look at partial deregulation as one way to allow the planting of a GE crop.

Mr. KUCINICH. Are you talking about the cases that were struck down by Federal district courts?

Ms. WRIGHT. Yes, sir.

Mr. KUCINICH. That was at the request of the industry, right?

Ms. WRIGHT. Yes.

Mr. KUCINICH. OK. What's the—I'm still trying to figure out the basis for your view here today that a permit system which the GE crop would remain a regulated article and nevertheless not permit to you to place requirement on planting and preventing the spread of Roundup resistance in weeds.

Ms. WRIGHT. Unless we determined there a plant pest risk, we do not have it that expansive authority.

Mr. KUCINICH. So you're still stuck on one section of the act and haven't read the other.

Ms. Wright, isn't it true that the Department has had under development, a new biotechnology rule and that the rule was also under development during the previous administration?

Ms. WRIGHT. Yes.

Mr. KUCINICH. OK. And with the change in administration, can this Congress expect to see any differences in the Department's approach to herbicide-resistant weeds and the rule you're now working on.

Ms. WRIGHT. I can tell you that we're having internal discussions about our policies, and around coexistence, and that we just honestly cannot afford to look at options and alternatives that are not supportive of various cropping systems, including biotechnology, organic and conventional. They all play a very critical role in the health of our rural economy and in our agricultural economy.

Mr. KUCINICH. I know that was in your opening statement. I heard that. But it's not responsive to the question I asked.

Ms. WRIGHT. Can you ask your question again? Will you please restate your question?

Mr. KUCINICH. There has been a change in administrations, can we expect to see any difference in the Department's approach to herbicide-resistant weeds in the rule that you're now working on?

Ms. WRIGHT. I think we're looking at all—a lot of options, and we're going back and looking, considering the comments that were submitted. We're internally having discussions across the Department. We have a Secretary and an administration that's very committed to the idea of addressing the issues of coexistence, and that's as much as I can say today.

Mr. KUCINICH. See the thing that I'm concerned about—and I am really trying to give you the benefit of the doubt on what you're saying, the thing that I'm concerned about, is that when you go back to your talking points, you actually inadvertently shut the door on consideration of the science and experience that's been brought forward through the EPA's enforcement through the practical experience of farmers, through the NRC report. And so I'm trying to—because it's important that we understand—you've made it clear that the policy, you know, what the policy is, you haven't extended that to a legal interpretation, but if you're just saying well, you know, we have different ways of supporting agriculture, we're going to try to support them all.

But if you rest on that and don't go deeply into expressing to this subcommittee a concern that the extent to which herbicide-resistant weeds may represent an attack on the rights of farmers, the economic rights of farmers, the environment, if you don't articulate that, it causes me to pause.

Ms. WRIGHT. Well—out of all due respect, I would say that it's not that we don't recognize this as a bottom line issue for farmers and ranchers——

Mr. KUCINICH. It's what?

Ms. WRIGHT. It's not that we don't recognize this as a critical issue for farmers and ranchers, but I think this administration and USDA see biotechnology as being a very important tool for farmers to use in addressing some very critical issues, globally and here domestically. And all of the options that we look at have to be supportive of that, they have to encourage and support innovation in a smart way.

Mr. KUCINICH. Do they look the other way if there is a problem?

Ms. WRIGHT. No, I don't think so. We take our NEPA process and documents very seriously. In fact, the Secretary just approved a reorganization of our BRS services, we have a whole team, a new team, a whole program dedicated to NEPA now. We have a budget increase request before Congress for 2011, fiscal year 2011 of $5.8 million to hire new scientists. We take these issues very seriously. And as we learn more about the environmental impacts of this technology, we try to adjust and we try to make our rules and regulations.

Mr. KUCINICH. Just out of curiosity, you think—genetic—you just talked about the importance of biotechnology, is it your view, personally, that genetically engineered crops are the functional equivalent of conventional crops?

Ms. WRIGHT. Well, I'm not prepared to reflect on that.

Mr. KUCINICH. OK, that's fine. For the last couple of decades, the EPA and the USDA had pledged in various Memoranda of Under-

standing to promote integrated pest management. One of the key objectives of integrated pest management is preserving the efficacy of relatively benign pesticides and preventing herbicide resistance in weeds. Now I move to insert into the record one such Memorandum of Understanding from 2001.

Now, to the EPA, I want to address this question, does it concern the EPA from the perspective of integrated pest management that more and more acres of farmland are showing signs of infestation by Roundup-resistant weeds?

Mr. JONES. Yes, it does.

Mr. KUCINICH. Now, in general, isn't proliferation of Roundup-resistant weeds across millions of acres of farmland a setback for integrated pest management?

Mr. JONES. Sure.

Mr. KUCINICH. And to the USDA, does the USDA agree with the EPA that from the perspective of integrated pest management to widespread infestation of Roundup-resistant weeds constitutes a setback?

Ms. WRIGHT. I'm sorry, can you please repeat that?

Mr. KUCINICH. Does the USDA agree with the EPA, which just responded yes, that the proliferation of Roundup-resistant weeds across millions of acres of farmland is a setback for integrated pest management. I asked you, do you agree with the EPA from the perspective of integrated pest management, the widespread infestation of Roundup resistance weeds constitutes a setback?

Ms. WRIGHT. Possibly, yes.

Mr. KUCINICH. Mr. Jones, in communication with the majority staff, the EPA has stated that the USDA did solicit EPA's input in its Environmental Impact Statement for Roundup Ready Alfalfa, but as we've already seen, the Environmental Impact Statement will not consider any measures for preventing the spread of Roundup-resistant weeds.

USDA testified that EPA raised no objection to their draft environmental impact strategy on alfalfa, which USDA characterizes as meaning, "The EPA had no concerns."

Is that a complete representation of EPA's comments to USDA on the Roundup-Ready Alfalfa Environmental Impact Statement?

Mr. JONES. Chairman, to be fair to my colleagues at USDA——

Mr. KUCINICH. I'm asking you to answer the question, not to be fair, but to answer the question.

Mr. JONES. The answer to the question is that an Agency's formal response that went through our office of Federal activities, we did not raise the issue of insects—I'm sorry, herbicide resistance. In informal conversations, when we've had a number of them, and they continue to this day.

Mr. KUCINICH. So you did raise a concern about weed resistance management; is that right?

Mr. JONES. That's correct.

Mr. KUCINICH. Now Ms. Wright, this is somewhat at a variance with your written testimony. And contrary to that, does the USDA now acknowledge that the EPA did, in fact, express concern about the weed resistance management issue in the alfalfa Environmental Impact Statement?

Ms. WRIGHT. Yes, we did.

Mr. KUCINICH. Mr. Jones, did USDA ever ask EPA to offer its expertise in preventing pest resistance in the context of the USDA's preparation of an environmental impact statement for deregulating GE alfalfa?

Mr. JONES. Once we raise the concerns that we have identified through informal mechanisms that led to an ongoing dialog between USDA and EPA to address those, and so——

Mr. KUCINICH. Did they ask you to offer your expertise?

Mr. JONES. That is correct.

Mr. KUCINICH. What did they ask you to do?

Mr. JONES. When we raised our—we raised some issues associated with resistance management, and as it was characterized in EIS. And the Department said to us, you've raised some very good points, let's talk about that, we want to understand this better. And those conversations continue, as I said, to this day, and I believe will continue until we feel like we're on the same page on that issue.

Mr. KUCINICH. Well, given the scientific verification of the rapid spread of Roundup-resistant weeds, do you think it might be justifiable for the EPA and the USDA to revisit the question in preparation for the final environmental impact statement for Roundup Ready Alfalfa, Mr. Jones?

Mr. JONES. I believe that's what we're doing right now.

Mr. KUCINICH. And to Ms. Wright, given the EPA's successful effort thus far in preventing the Bacillus thuringiensis resistance in pests, wouldn't it make sense for the USDA to want to utilize the EPA's expertise to help regulatory means to prevent and mitigate Roundup resistance in weeds?

Ms. WRIGHT. Yes. And if it's OK with you, I'd like to ask Sid Abel to address more of the specifics around how we are working with EPA.

Mr. KUCINICH. He's sworn, he can do that.

Mr. ABEL. We are—right now we're working very directly at the staff level with our partners at the EPA to address specifically the issue of glyphosate tolerance among weeds. We agree, both with EPA and with other parts of our Federal partners, that this is a serious issue for farmers. It's also a serious issue for the technology. We see that this is a very favorable compound to be used in controlling weeds, and to preserve that technology is very important to us. So we've entered into these discussions with EPA at the staff level with the Weed Science Society of America, and with others, universities and extension agents to get a better handle on the extent to which glyphosate tolerance is occurring out there, not just in GE crops, but also in conventional crops. We believe that by going through this process, we'll be able to put forward some strategies for managing these crops in a way to preserve these technologies into the future.

Mr. KUCINICH. Have you read section 412 of the act?

Mr. ABEL. It has been a while, but yes, sir, I have.

Mr. KUCINICH. Would you read it again?

Mr. ABEL. Yes, I would.

Mr. KUCINICH. I want to thank the members of this panel for participating in this important discussion. And this committee will

continue to retain jurisdiction over this matter, which means that there will be more hearings.

We are very interested in the policies of the USDA as it affects the environment, farmers. And I'm grateful for your presence here today and for the EPA's continuing work in this area as well.

The first panel is dismissed and I'm going to call the second panel to come forward, and we will begin the second panel in a couple of minutes as soon as you're all in place.

I am going to read the introductions at this moment while staff is getting set up. I want to welcome to this subcommittee Congresswoman Diane Watson, Ambassador Watson from California, for gracing this hearing.

We have here today Mr. Steve Smith. Mr. Smith, welcome. Mr. Smith is director of agriculture at Red Gold, Inc., the largest privately-held canned tomato processor in the country. In his position he works closely with their growers in Indiana, Ohio and Michigan. He is co-chair for Red Gold's new sustainability initiative and serves on the Sysco Corp.'s national sustainability advisory board. Mr. Smith has served on the Purdue University dean of agriculture advisory board, the board of directors of the Mid-America Agriculture and Horticultural Services, as director of the American Fruit and Vegetables Processor and Grower's Coalition, and as an inaugural member of the Indiana Department of Agriculture advisory board. Thank you for being here.

Dr. Phil Miller currently serves as a vice president in the Monsanto Co. He leads the regulatory group which is responsible for the development of health and safety research on new agricultural and biotech products, global regulatory approvals, product safety defense, and management of numerous key scientific and regulatory issues. Dr. Miller joined Monsanto in 1994 and has held numerous roles in chemical discovery in biotechnology research and development. Some key roles include director of biotechnology, crop enhancement and crop genomics research, and Monsanto's Sirius Research Collaboration League.

Thank you for being here, sir.

Next is Mr. Bill Freese who is science policy analyst with the Center for Food Safety, a D.C.-based nonprofit group. Mr. Freese has written and lectured extensively on the science regulation and societal implications of agricultural biotechnology for over a decade. In 2004 he coauthored a peer-reviewed scientific paper on common myths about U.S. regulation of genetically engineered crops. Mr. Freese is a frequently quoted expert on agriculture biotechnology in the mainstream media as well as the scientific press. He has reviewed and critiqued numerous petitions for deregulation of herbicide-resistant crops, the subject of today's hearing.

Finally, Mr. Jay Vroom, who is president and chief executive officer of CropLife America, the largest national trade organization representing developers, manufacturers, formulators, and distributors of agricultural pesticides across the United States. Mr. Vroom has held his position since 1989. Previously Mr. Vroom served as executive vice president and chief executive officer of National Fertilizers Solutions Association in St. Louis, Missouri. He began his professional career on the staff of the Fertilizer Institute.

As with the previous panel, I want to make you aware that it is the policy of the Committee on Oversight and Government Reform to swear in all witnesses before they testify. I ask that you gentlemen rise and raise your right hands.

[Witnesses sworn.]

Mr. KUCINICH. Let the record reflect that each of the witnesses has answered in the affirmative.

I would now ask that each witness give an oral summary of your testimony. I would ask that you keep the summary under 5 minutes. And I remind you that your entire written statement will be included in the record of the hearing and will be distributed to the members of this committee as well as to the media. We are going to begin with Mr. Smith. You are the first witness. I would ask you to proceed.

STATEMENTS OF STEVE SMITH, DIRECTOR OF AGRICULTURE, RED GOLD TOMATO; PHIL MILLER, VICE PRESIDENT, GLOBAL REGULATORY, MONSANTO CO.; BILL FREESE, SCIENCE ADVISOR, CENTER FOR FOOD SAFETY; AND JAY VROOM, CEO, CROPLIFE AMERICA

STATEMENT OF STEVE SMITH

Mr. SMITH. Thank you, Chairman Kucinich, and members of the Domestic Policy Subcommittee. I thank you for the opportunity to present to you some important concerns about the pending release of dicamba-resistant soybeans.

My name is Steve Smith, director of agriculture for Red Gold, the largest privately-held canned tomato processor in the United States. Red Gold is based in Indiana and has three processing facilities. Our tomatoes are grown by 54 family farming operations in Indiana, Ohio, and Michigan.

Our concerns about the upcoming increased use of dicamba are not just about tomatoes but all fruit and vegetable crops and rural homeowners living near local farms. The use of dicamba is not new. It is effective, it is a great weed killer, and it is economical to apply. So many may be wondering why a product that is effective, proven, and economical is not the No. 1 herbicide in use today. The answer is simple: dicamba has also proven itself to move off target and injure adjoining crops, so it is not currently widely used.

New technology is good and needs to be pursued, but must be examined for unintended consequences. At one time the conventional wisdom thought it was a good idea to use lead in paint. The theory of dicamba-tolerant soybeans might appear sound on the surface—the ability to kill weeds is proven—but the potential damage to other sectors of agriculture and rural homeowners demands that we take a closer look at this particular advance.

When put in the spotlight, the answer will become abundantly clear: The widespread use of dicamba is incompatible with Midwestern agriculture. dicamba is highly vulnerable to offsite movement in three forms: direct drift, volatilization, and spray-tank contamination.

You would think that the risk of direct drift could be completely controlled by good management practices such as spraying in little or no wind or when the wind was blowing away from sensitive

crops such as tomatoes. But unfortunately, that is not always the case. Red Gold has suffered over $1 million in drift claims over the last 4 years. A reduced application window has forced otherwise good farmers to spray on windy days when they know they shouldn't.

But I want to focus on volatilization because it is the real issue that makes dicamba a danger to Midwestern agriculture. Volatilization occurs when the active ingredient evaporates and then can be moved with the surrounding air mass for up to 4 days after application; and its killing capabilities can spread up to 2 miles or more in certain geographic areas such as in a valley.

Even the best farmer, the most conscientious farmers can't control or predict what will happen for up to 4 days after application. Ironically, the very conditions that minimize direct drift actually maximize volatilization: little or no wind, high temperatures, and high humidity—normal conditions for when this product is applied in June and July.

A good neighbor that awakens early in the morning to spray before the winds pick up would be at the highest risk of causing volatilization injury.

In other testimony offered, we learn that new formulations of dicamba will reduce the risk of volatilization. We believe those claims to be overly optimistic as even the newest formulations are still proven to move off target. It simply is impossible to control or predict its movement. The science is clear and settled in regard to dicamba's susceptibility to off-target movement due to volatilility.

If, as you might hear from others, the risks of off-target movement of dicamba due to volatilization are low and can be controlled through improved product stewardship and formulations, it only makes sense that those who will profit from the sale of this seed technology and the makers of dicamba should willingly step up to the plate and establish an indemnity fund to cover crop losses and homeowners' claims for damages.

If they are unwilling to cover potential losses, is this an admission that the safety of this technology is not as safe as we have been led to believe? The Midwest is the home to a unique system of family farms that are known as the bread basket of the world. The introduction of dicamba-tolerant soybeans is a classic case of shortsighted enthusiasm over a new technology, putting this region at unneeded risk, and blinding us to the reality of damage that is sure to come.

Even the best, the most conscientious farmers cannot control where this weed killer will end up. Increased dicamba usage made possible through the introduction of dicamba-tolerant soybeans is poor public policy and should not be allowed.

Thank you for the opportunity to present my concerns to you today. I will be happy to answer any questions you might have concerning this topic.

Mr. KUCINICH. Thank you, Mr. Smith.

[The prepared statement of Mr. Smith follows:]

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Testimony before Congress

Steve Smith

September 30, 2010

Domestic Policy Subcommittee

of

Committee on Oversight and Government Reform

Dennis J. Kucinich, Chairman

Deployment of Dicamba-resistant soybeans and what it will mean to canned and frozen food processors and specialty crop growers in the Midwest

Thank you Mr. Chairman and members of the Domestic Policy Subcommittee, for the opportunity to present to you some important concerns about the pending release of Dicamba-resistant soybeans. My name is Steve Smith, Director of Agriculture for Red Gold, the largest privately held canned tomato processor in the United States, based in Indiana with three processing facilities located there. We purchase tomatoes from 54 family farming operations in Indiana, Ohio and Michigan.

In my capacity at Red Gold, I am privileged to interact with a wide segment of the specialty crop industry in the Midwest, home to a diverse array of canned and frozen fruit and vegetable production, as well as local fresh market and organic production marketed directly to local consumers. A growing wine grape industry has also begun to flourish in Indiana, adding to our diverse production base. These specialty crop industries are worth 254 million dollars to the State of Indiana, providing thousands of jobs throughout our state. These groups, and nearly every food crop represented on the grocers shelves and produce stands, all have an intense interest about the effects of the widespread use of dicamba and the devastation it will cause to the sensitive crops grown in our region.

My life experiences include growing up in central Indiana on a traditional family farming operation, graduating with distinction from Purdue University in Agriculture and being named a Distinguished Alumni in 2009, serving as a Regional Sales Manager for a seed corn and soybean

company, holding a Certified Crop Advisor certificate and having 22 years of experience in the specialty crop industry with Red Gold. **I am convinced that in all of my years serving the agricultural industry, the widespread use of dicamba herbicide possesses the single most serious threat to the future of the specialty crop industry in the Midwest.**

The use of dicamba is not new. It has been a labeled product for use on corn for decades. It has been proven effective for many uses and is not particularly vulnerable to developing resistant strains of weeds. It is economical to apply.

So many may be wondering why a product that is effective, proven, and economical is not the number one herbicide in use today. The answer is simple. Dicamba has proven itself to move off-target and cause injury and yield reductions to soybeans and so in a large sense, it is rarely used. Farmers respect their neighbors and know they are at risk of causing injury if they use dicamba, so it is not widely and routinely used in corn production. However, when soybeans become tolerant to dicamba, it is very likely that the amount of dicamba used in corn production will skyrocket when the fear of soybean injury is eliminated. As an example, when glyphosate soybeans were first introduced, there was significant injury due to drift on corn the first few years. It didn't take long for applicators and farmers to gain a higher degree of respect for the injury that could occur. But once the widespread use of glyphosate resistant corn became common, that level of caution began to erode because it didn't really matter if you drifted onto your neighbor, because their crop was also glyphosate resistant. I also predict a similar fate for dicamba use once soybeans are made tolerant. With no fear of soybean injury, the use of dicamba on corn acreage will dramatically increase, raising the overall exposure of sensitive crops to injury. Because dicamba is deadly to weeds and cheap to use, it is a sure prediction that dicamba use will increase dramatically, followed by escalating crop losses.

In other testimony offered, you may hear that new formulations of dicamba will reduce the risk of volatization. Volatization is the process where the active ingredient literally evaporates into the air and can relocate as the air moves. We believe those claims to be overly optimistic as the characteristics of this molecule have been well documented for about 50 years, and even the newest formulations are still proven to move off-target.

Some might interpret this testimony to imply that I am opposed to advances in technology, and that progress is not a thing to be pursued. Nothing could be further from the truth. The technological progress made in the last twenty years is responsible for us having the world's safest,

most nutritious and affordable food supply. Many might suggest that technology has taken us the wrong direction and is harming our environment and the sustainable nature of agriculture. I would suggest just the opposite to be true when good stewardship practices are implemented and followed. Productivity is a good thing. It lifts our standard of living. If Red Gold can produce a nutritious product for our consumers at a cost they can afford, everyone wins.

However, technological advances need to be critiqued and examined for their overall contributions and unintended consequences. Just because we can do something doesn't mean that we should. At one time, the conventional wisdom thought it was a good idea to use lead in paint. The theory of dicamba tolerant technology might appear sound on the surface. The ability to kill weeds is proven. But the potential damage to other sectors of agriculture and rural homeowners demands that we look further at this particular advance. There may even be geographic areas of the country where this technology would cause only minimal harm and adequate protective measures might even be put into place to protect the public's interest, but definitely not in the Midwest. If dicamba tolerant soybeans are released onto the market place in the Midwest, they will be used and cause harm to our traditional cropping system. Anything that has the potential to cause that type of widespread crop damage should have intense discussion and oversight. When that occurs, the answer will become abundantly clear. **The widespread use of dicamba is incompatible with Midwestern agriculture.**

Since the introduction of glyphosate resistant crops, the pattern of weed control in the Midwest has changed from predominantly pre-plant applications of herbicides, to almost entirely a post-plant, in-season application practice. The effects of this paradigm shift in herbicide applications has affected our company and family growers in a very negative way, due to the potential for direct drifting of spray material onto our tomato fields from applications during windy conditions. The majority of herbicide applications were historically made prior to the planting of most specialty crops, so the drifting of products caused little or no harm. However, the transformation to herbicide applications during the growing season in June and July has put drift prevention at the forefront of concerns to sensitive crop producers of all kinds. Over the last four seasons, our company and growers have been involved with cropping losses exceeding a million dollars due to glyphosate drift.

In addition to the financial loss to our growers, Red Gold is placed in considerable risk of supply disruption due to the drifting of post-applied herbicides. Unlike commercial grain

production, if our tomatoes are damaged, processing tomatoes are not available to be purchased on the open market to make up the losses. We suffer from the risk of having inadequate product for our customers, which could result in the permanent loss of business due to lack of supply. We willingly have chosen to deal with all the traditional production risks and plan our business to minimize those risks, but we are helpless to anticipate the cropping losses that occur due to the misapplication and drift of glyphosate onto our tomatoes. Good stewardship by neighbors and applicators has been fairly successful in preventing direct drift. Unfortunately, with dicamba tolerance being added to soybeans, a whole new challenge far more dangerous and unpredictable than direct drift is knocking on our door.

With glyphosate, crop injuries are the result only from direct drift. Glyphosate is not a volatile compound that will pick up and move in the days or hours following application. Dicamba on the other hand, is highly vulnerable to off-site movement in three forms:

1. **Direct drift.** Dicamba is readily moved by the wind during application. Direct drift is in theory, always preventable, by either applying within label restrictions of wind or by applying when the wind direction would not result in a threat to a sensitive crop.
2. **Volatization**. Dicamba is proven to volatize, or more simply, for the active ingredient to evaporate into the air where it is easily moved off-target as the air mass moves. It can move up to two miles in distance, or even more in certain regions such as down a valley. As opposed to direct drift, the environmental conditions that effectively minimize drift, ironically, **maximizes** the potential for volatilization. Those conditions are high temperatures and high humidity, conditions that are common during a Midwestern summer when a post-applied application of dicamba would be most likely. A producer trying to be a good neighbor, who awakens early so he can spray next to our tomato field before any wind picks up, actually would be applying the material in the most vulnerable fashion for volatilization to occur. Because this can occur for up to four days following the initial application, an applicator cannot adequately take measures to prevent both drift and volatilization. He is in a no-win situation, as is every sensitive crop within a two or more mile radius where dicamba would be applied. **The science is clear and settled in regard to dicamba's susceptibility to off-target movement due to volatility.**
3. **Spray tank contamination.** Dicamba has characteristics that make it extremely hard to get completely cleaned out of spray tanks following use. Some commercial applicators have

told me that they refuse to spray dicamba because they risk damaging the crops of their customers. Even small quantities left in a spray tank will injure crops.

Crop losses caused by direct drift are a violation of label restrictions; however, crop losses caused by volatization are not a violation of the pesticide label. The weather conditions during the application are the deciding factors of misapplication, not what happens at a later time. There will be no recourse for growers or processors for crop losses resulting from volatilization. It is likely that the source of losses might never even be completely pinpointed because under widespread use, the problem could have come from a multitude of sources. Our very livelihoods, and those of our growers, are under severe risk if the widespread use of dicamba is permitted.

The risk of off-target movement is not limited to only tomatoes and other fresh market produce. Growers of non-dicamba tolerant soybeans will be at risk. Organic producers not only risk the loss of produce for sale, but also risk their organic certification for three years if off-target movement of dicamba would occur. Grape and vineyard production is extremely vulnerable and production could be lost for multiple seasons if a serious off-target movement occurred. This would be devastating for many of the most vulnerable small farm producers. These are the farms that produce the fruits and vegetables that become our main weapon in our fight to reduce our national obesity epidemic.

The nature of the common layouts of Midwestern farms, places all of these sensitive crops in close proximity to soybean production where dicamba would be used in a widespread manner. But in addition to the cropping risks posed by the widespread use of dicamba, the desire for country living environments has driven the trend for home construction out into the countryside. Home gardens and landscaping would be extremely vulnerable to off-target movements because of their proximity to the farming areas of the Midwest. In an atmosphere of consumers worried about where their food comes from and worries of residues from all crop protectants in the food supply, damage caused by the off-target movement of dicamba would give all of agriculture a black-eye if home gardens or landscaping were damaged.

If the risks of off-target movement of dicamba due to volatization are low and can be effectively controlled through product stewardship and formulations, it only makes sense that those who will profit from the sale of this seed technology and the makers of dicamba should willingly step up to the plate and establish an indemnity fund to cover crop losses and homeowner's claims

for damages. If they are unwilling to cover potential losses, is this an admission that the safety of this technology is not as safe as we would be led to believe?

Agriculture needs to be building up the confidence of producers and consumers instead of giving them cause for alarm. The Midwest is the home to a unique system of family farms that have been the breadbasket of world agricultural production. The introduction of dicamba tolerant soybeans is a classic case of short-sighted enthusiasm over a new technology blinding us to the reality that is sure to come. **Increased dicamba usage, made possible through the introduction of dicamba tolerant soybeans, is poor public policy and should not be allowed.**

Thank you for the opportunity to present my concerns to you today. I will be happy to answer any questions you might have concerning this topic.

Mr. KUCINICH. Mr. Miller, please proceed.

STATEMENT OF PHIL MILLER

Mr. MILLER. Chairman Kucinich and members of the subcommittee, thank you for inviting me to testify on matters relating to modern agricultural technology.

I work at Monsanto whose only focus is agriculture. I spent much of my youth in a small agricultural community in Lawrence County, Illinois, where I had the privilege of helping my grandfather on his farm. I also have a farm in Nebraska. Through my experiences, I have a great appreciation for what the American farmer has and can achieve with the right tools and a willingness to adopt new technologies and practices.

I currently serve as vice president of regulatory, with more than 500 scientists in my organization, and it is responsible for the global product approval and stewardship.

The topic of today's hearing is an important one. The world population is growing. In the next 40 years or so, there will be 9 billion people on our planet. That is 3 billion more people that will show up to the dinner table, and many will want to use the foods we have grown up with. To put it in context, that is the equivalent of three more Chinas. The challenge is: How do we do it using fewer resources?

Farmers are increasingly being asked to produce more with less, and helping to do this is what Monsanto is all about. Our company has a commitment to sustainable agriculture. We will do our part to help farmers double yield in the core crops of corn, cotton, and soybeans between 2000 and 2030, while producing each bushel or bale with one-third fewer resources.

Just as important, in doing so we will help farmers earn more, and improve the lives of their families and rural communities globally. Agricultural innovation has provided farmers with improved agronomic practices, advances in breeding, and novel traits through modern biotechnology, which increases yield and profits.

In 1996, the Roundup Ready system was first introduced into soybeans. The Roundup Ready system was attractive to farmers because it offered superior crop safety and the use of a familiar and proven herbicide that controls more than 300 weeds. In Roundup Ready Soybeans, glyphosate sprayed after the crop's weeds emerge provide a level of weed control and ease of use that surpasses other options.

Importantly, in addition to the benefits provided in weed control, the Roundup Ready system has made the adoption of conservation tillage practices feasible. Conservation tillage contributes to the long-term sustainability of farming practices.

Before the Roundup Ready system was introduced, the environmental benefits of conservation tillage were documented, but adoption by growers had been limited. The broad enrollment in conservation tillage due to the Roundup Ready system has led to the reduction and extensive plowing and tillage which has significantly reduced the loss of topsoil due to erosion, improved soil structure, reduced runoff of sediment and fertilizer, reduced on-farm fuel use, reduced CO_{50} emissions, and increased carbon sequestration in the soil.

Controlling weeds is paramount in maintaining and improving crop productivity. Unlike insects and diseases which occur in some years and not others, weeds occur in crops every year. Experts recommend using multiple herbicides to provide more than one mechanism of action. Applying multiple mechanisms of action reduces the likelihood of a resistant weed population developing because there is a low probability that a particular weed within a population would have resistance to both mechanisms of action.

In addition, farmers may choose to use mechanical or cultural techniques in addition to or in place of herbicides. The specific program employed would depend on the farmer's choice and the best management practices on his or her farm.

Monsanto has shared interest with farmers in effective weed management. The proactive adoption of best management practices based on the principle of diversity in weed management will improve weed control, help ensure that conservation tillage systems are sustainable, and that the yield, economic, and environmental benefits are fully realized.

As I stated at the beginning of my remarks, Monsanto's only focus is agriculture. If farmers don't succeed, Monsanto doesn't succeed. That is why as we bring new technology to the market, we value growers' input, such as Mr. Smith who is here today, who we have invited and has become a member of our dicamba advisory council. We are committed to invest and develop seed and trait systems to provide farmers with effective, affordable, convenient and sustainable agricultural solutions, including weed control.

Thank you, Mr. Chairman, for your time and attention today. I look forward to answering your questions.

Mr. KUCINICH. Thank you for your testimony.

[The prepared statement of Mr. Miller follows:]

**Written Statement of Philip W. Miller on behalf of Monsanto Company
for the September 30, 2010 hearing of the Domestic Policy Subcommittee
of the US House of Representatives Oversight & Government Reform Committee**

Chairman Kucinich, Ranking Member Jordan and Members of Subcommittee, thank you for inviting me to testify on matters relating to modern agricultural technologies.

I work at Monsanto, a company 100 percent focused on agriculture. We develop improved seed through advanced breeding as well as biotechnology. We work with others to build cropping systems that help farmers produce more bountiful harvests on each acre, with plants that can protect themselves from many pests. We enable weed control within conservation tillage systems that reduce soil erosion, water loss and carbon emissions.

Using these tools, American farmers reach unparalleled levels of productivity to feed and clothe more people with every acre. They are driving the U.S. economy, while helping to meet the demand for food, fuel and fiber that is increasing with global population and income levels.

Our company has a three-pronged commitment to improve sustainable agriculture: We will do our part to help farmers double yields in our core crops of corn, cotton and soybeans between 2000 and 2030, while producing each bushel or bale with one-third fewer resources (such as land, water and energy) in aggregate. And, just as importantly, in so doing we will help farmers to earn more and improve the lives of their families and rural communities.

We made this commitment in recognition that we are privileged to work in an amazing industry – agriculture – that is at the heart of some of our planet's biggest challenges, ranging from hunger, malnutrition and rural poverty to land degradation, water scarcity and climate change.

By the end of this day, the world will have 210,000 more people than the day before who are in need of food, fiber and fuel from agriculture. Experts have suggested that the requirements of food production over the next 50 years will exceed the production we have achieved in the past 10,000 years, cumulatively. Irrigated crop production accounts for 40 percent of the world's food supply; however, with global water use growing at twice the population rate, farmers are becoming more challenged to secure enough water for their crops. In the face of these challenges, the agricultural sector needs to focus on farm management practices and technologies that can improve productivity while conserving natural resources and minimizing the global footprint of agriculture. Monsanto is committed to helping farmers become more productive and sustainable each year.

Agricultural innovation has provided farmers with improved agronomic practices, advances in crop breeding, and novel traits through modern biotechnology to increase yields and profits.

Farmers utilize a wide range of technologies on the farm to maximize yields while minimizing the risk of crop failure.

Controlling weeds is paramount in maintaining and improving crop productivity. Unlike insects and diseases, which occur in some years and not others, weeds are ubiquitous. They return every year from millions of seeds, tubers or rhizomes, deposited in the soil annually from weeds that survive in the field, fence rows, and irrigation ditches, and spread from field to field on planting, crop treatment and harvesting machinery.

In the 1930's, farmers relied on deep plowing and tillage for weed control but excessive tillage caused devastating soil losses due to wind erosion and run-off. The invention and commercialization of synthetic chemical herbicides over the past 60 years has offered growers new tools for controlling weeds.

The herbicide glyphosate, introduced in the early 1970's, expanded the weed management options available to farmers. Glyphosate controlled a broad spectrum of weeds more effectively than combinations of herbicides used previously, resulting in improved weed control for farmers and improved farm management and profits. However, because glyphosate killed nearly all leafy green plants, it had to be used in ways so that it did not come into contact with crops. Glyphosate controls more than 300 annual and perennial grass and broadleaf species, providing the widest spectrum of control compared to any other herbicide. Farmers quickly recognized the benefits of glyphosate herbicides.

In 2000, Monsanto's US patent on glyphosate expired. Today, farmers in the United States have several choices of generic glyphosate herbicide products. Monsanto continues to sell Roundup® brand glyphosate herbicide products.

In 1996, the Roundup Ready® system (seeds modified to be tolerant to glyphosate and which allowed the use of glyphosate for weed control in the crop) was first introduced in soybeans. The Roundup Ready system was attractive to farmers because it offered superior crop safety, and the use of a familiar and proven herbicide that was active on a broad spectrum of annual and perennial weeds (grasses and broadleaves). In Roundup Ready soybeans, glyphosate sprayed once or twice in a season after the crops and weeds emerged provided a level of weed control and ease of use that surpassed other options.

The same was true for glyphosate tolerant corn, cotton, and canola that were commercialized in the late 1990's. Importantly, in addition to the benefits provided in weed control, the Roundup Ready system has made the adoption of conservation tillage practices feasible on many more farms. Conservation tillage contributes to the long-term sustainability of farming practices. Before the Roundup Ready system was introduced, the environmental benefits of conservation

tillage, including low-till and no-till practices, were documented but adoption by growers had been limited, in part, because they could not get acceptable weed control without tillage in many instances. The use of herbicides and in particular glyphosate for weed control instead of extensive plowing and tillage has significantly reduced the loss of topsoil due to soil erosion, improved soil structure with higher organic matter, reduced runoff of sediment and fertilizer, reduced on-farm fuel use, reduced CO_2 emissions, and increased carbon sequestration in soil.

Over the past 20 years, the number of corn, soybean and cotton acres in conservation tillage has nearly doubled to a total of 82 million acres in 2008. Farmers have consistently indicated that Roundup Ready technology has been a critical innovation allowing them to shift to conservation tillage. In 2001, a survey by the American Soybean Association (ASA) of its members revealed that the adoption of Roundup Ready technology was the primary reason farmers reduced tillage in soybean production.

The topic of herbicide resistance in weeds is of interest to the Subcommittee. A herbicide resistant weed will survive an application of a herbicide that will normally kill the weed. Within a weed population, individual plants with resistance to a particular herbicide and/or herbicide class can occur naturally. Such biological variability is not caused by use of the herbicide. Subsequent use of the herbicide merely selects for those plants that already have the resistance.

Weed resistance to herbicides is not new. Guided by continuing research, new strategies to manage herbicide resistance have been developed and continue to evolve. Monsanto, other companies, universities, government agencies, and crop commodity groups are working to provide farmers with the most up-to-date recommendations and to educate them on the importance of adopting practices to manage herbicide resistance.

There are inherent differences among the herbicide classes. Some herbicide classes are more prone to resistance than others. The first instance in the United States of a weed being determined to have resistance to a herbicide occurred in 1957 when spreading dayflower in Hawaii was found to be resistant to the herbicide 2,4-D. Although resistant weed populations have been known for over 50 years, 2,4-D is still widely used around the world and is an ingredient in products familiar to consumers such as Weed B Gone. The first weed displaying resistance to glyphosate was annual ryegrass discovered in Australia in 1996. In 1998, ryegrass resistant to glyphosate was observed in California where glyphosate was being used for weed control in orchards.

Today there are 19 weed species worldwide with confirmed resistance to glyphosate, 10 of which are present in the U.S. This compares to 107, 68, and 37 species with confirmed resistance to the three other major classes of herbicides (ALS inhibitors, PSII (triazines) and ACCase inhibitors, respectively) used by many farmers growing soybean, cotton and corn in the U.S. As with glyphosate, farmers continue to use these products because they provide significant value in

their weed management programs. As weed resistance occurs, farmers adjust their weed management practices. The best way to manage weed resistance on a particular farm depends on the particular circumstances on that farm.

Weed resistance is an herbicide issue, not a biotech crop issue, and is dependent on how herbicides are used. Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Federal Government's Coordinated Framework for regulating biotechnology-derived products, EPA is the agency charged with analyzing the potential environmental impacts from the use of a pesticide. Specifically, EPA must evaluate whether the use of a pesticide in accordance with instructions on its label will result in "unreasonable adverse effects [to humans or] the environment." EPA balances the risks and benefits of pesticide products when applying this standard to determine whether to register a particular pesticide for a specific use.

Before an herbicide is authorized for a particular use, including over the top of a herbicide-tolerant crop, EPA must register that use in accordance with FIFRA. Since its introduction in the 1970's, EPA has regulated the use of glyphosate and for over fifteen years, EPA has registered glyphosate for use over the top of Roundup Ready crops.

EPA recognizes and has addressed weed resistance as an issue requiring attention. The Agency has issued guidance to pesticide registrants concerning weed resistance management information on pesticide labels. This guidance instructs registrants on information to provide to farmers regarding the mechanism of action of the herbicide and recommendations on practices to implement for delaying herbicide resistance. Monsanto follows EPA's guidance on its glyphosate labels and goes beyond EPA's specific guidance in providing recommendations to farmers.

Monsanto is actively evaluating and reevaluating herbicide resistance in order to refine further the best proactive management practices. Over the last 5 years Monsanto has invested more than $30 million dollars in collaboration with academics in the U.S. alone to study developments in resistance to glyphosate and improve management practices. EPA, USDA-ARS, and others in industry are also devoting resources to actively address herbicide resistance.

Today there is broad agreement among public and private sector scientists on practices that can minimize the potential for additional weeds developing resistance to herbicides. These practices were highlighted in a National Research Council Report issued in April. A summary of these best management practices is published on the Herbicide Resistance Action Committee (HRAC) website (www.hracglobal.com) and the Weed Science Society of America (WSSA) website. Experts recommend using multiple herbicides to provide more than one mechanism of action. Using multiple mechanisms of action reduces the likelihood of a resistant weed population developing because there is a low probability that a particular weed within a population would

have resistance to both mechanisms of action. In addition, farmers may choose to use mechanical and/or cultural techniques in addition to, or in place of, herbicides. In many cases a proactive weed management program, in fields where no resistant weeds are present, will be identical to the weed control practices that a farmer would employ to control resistant weeds. The specific program employed will depend on the particular circumstances on that farm.

Even in locations where there are glyphosate resistant weeds, glyphosate continues to provide significant benefits to farmers and continues to be recommended by academics and extension agents as a key component in weed management systems. Glyphosate provides a foundation for economical and effective weed control in a diversified weed management program.

The need for proactive management of weed resistance continues to be addressed in many diverse venues. Weed scientists have learned from over 30 years of research that there is more than one way to manage herbicide resistance. University and industry experts believe that the best way to influence grower behavior is through intensive training and education programs. Monsanto, university/cooperative extension services, and other companies have devoted significant time and resources to grower/retailer education and training programs. Other organizations are also involved. For example the National Association of Conservation Districts and USDA's National Resources Conservation Service (NRCS) have brought together weed scientists and soil conservation officials from the south, southeast and mid-west to explore opportunities to further expand outreach to farmers on the need to implement best management practices for weed resistance. As growers are educated, more and more of them are adopting diverse weed control practices.

The Weed Science Society of America, in particular, has been active in coordinating activities of the scientific community regarding farmer education programs. Farm publications have also focused on the issue, raising awareness and serving as a means for public and private sector scientists to promote best management practices. These efforts are also leading more farmers to adopt diversified weed management programs on their crop acres.

In addition to farmer education and training about on-farm weed control practices, many companies are investing in the development of new weed control tools for farmers. At Monsanto, some specific technologies under development include new formulations of existing herbicide products and the development of new herbicide tolerant traits for soybeans and cotton plants that will provide additional options for weed control practices.

For example, Monsanto has been in the process of developing crops tolerant to dicamba because the ability to use dicamba in the Roundup Ready system would give growers more weed control options and flexibility. With dicamba tolerant soybean, for instance, the grower has the option to use dicamba as an effective weed control treatment prior to planting and can then plant soybeans without further delay. Furthermore, the ability to use glyphosate and dicamba together

throughout the growing season enables growers to manage resistant weeds and improve control of tough broadleaf weeds.

After more than 40 years of use there are four plant species with populations that are resistant to dicamba in the U.S. and Canada, and 5 worldwide. Dicamba is a member of the auxin family of herbicides.

Proper stewardship of dicamba in dicamba tolerant crops is imperative, and includes attention to guarding against the development of weeds resistant to dicamba and minimizing off-site movement of dicamba. To address weed resistance, we will continue training growers on the importance of a diverse weed management program and will only recommend the use of dicamba in combination with other herbicides. It is well known by scientists and farmers that off-site movement of pesticides occurs. Monsanto is aware of the concerns regarding the off-site movement of dicamba and is working with multiple stakeholders to address this issue. We are also working with other companies to develop improved dicamba formulations that reduce the potential for off-site movement.

Monsanto has a shared interest with farmers in effective weed management and in conservation tillage systems that are sustainable. The proactive adoption of best management practices based on the principle of diversity in weed management will improve weed control, help ensure that conservation tillage systems are sustainable, and that the economic and environmental benefits are fully realized. As we educate farmers, more and more are adopting diverse practices.

As I stated at the beginning of these remarks, Monsanto is 100% focused on agriculture. If the farmer doesn't succeed, Monsanto doesn't succeed. We are committed to developing seed and trait systems that provide farmers with effective, affordable, convenient, and sustainable agricultural solutions, including weed control. We recognize that proactive and diverse weed management practices are needed to preserve the benefits of the Roundup Ready system. To support best practices for sustainable weed management, Monsanto is broadly engaged in education and outreach efforts. We're also involved in public and private sector initiatives committed to sustaining the farmer and environmental benefits of herbicide tolerant crops and conservation tillage systems. And, Monsanto will continue to invest in research to provide our customers with products and recommendations that make them successful and promote sustainable agriculture.

Mr. KUCINICH. Mr. Freese.

STATEMENT OF BILL FREESE

Mr. FREESE. Yes. Chairman Kucinich and members of the subcommittee, thank you for inviting me here today to testify. I would just like to preference my remarks quickly to respond to something Ms. Wright and Mr. Miller just said about world hunger and productivity.

Actually, the subject here, Roundup Ready crops, do not have higher yields. That is a myth. It is basically designed to save time and save labor and help farmers get bigger. Also, there is an increase in pesticide use with these crops, actually quite substantial, not a decrease. And the conservation tillage benefits that Mr. Miller mentioned, conservation tillage was mostly adopted before the introduction of these Roundup Ready crops.

Just as Roundup Ready crops were being introduced in 1997, Monsanto scientists published a paper in which they presented all of the reasons weeds were not likely to evolve resistance to glyphosate. It is not the first time they have been wrong, and they turned out to be disastrously wrong. As discussed in part 1 of this hearing in July, unregulated use of these crop systems has triggered an epidemic of glyphosate-resistant weeds, and it fostered sharp increases in herbicide use, greater use of soil-eroding tillage operations, and is substantially raising weed control costs for evermore growers.

Now Monsanto and other pesticide firms assure us that multiple herbicide-resistant weeds are the solution to glyphosate-resistant weeds.

Dupont, for instance, even envisions a single crop resistant to seven or more different classes of herbicides. There are hundreds of millions of dollars being invested in resistance genes to just about every herbicide imaginable, including paraquat, for instance, and about half of the GE crops pending deregulation at USDA right now are herbicide-resistant.

We shouldn't let ourselves be misled again. These new herbicide-resistant crops are the wrong response to glyphosate-resistant weeds. Just very briefly, and I can go into detail in questions if you would like, but one reason is that they simply won't work. At best we will get a short-term reprieve until nature cleverly evolves resistance to the new and multiple herbicides deployed against them.

Second, farmers will pay in multiple ways through increasingly expensive biotech seeds and the multiple herbicide cocktails that come with them, and through crop damage, as Steve mentioned, or through purchasing the HR seed in order to defend oneself against drift.

Third, both public health and the environment will suffer from a substantially increased use of toxic herbicides such as 2,4-D and dicamba.

Finally, this new wave of crops diverts attention from truly sustainable weed control practices, which I would like to get to in a moment.

I think it is very clear that the glyphosate-resistant weed epidemic is a symptom of regulatory breakdown. We have USDA which regulates an herbicide-resistant crop, and the EPA the herbi-

cide; but no one regulates the combination, the herbicide-resistant crop, the herbicide system. And it is the system, the continual use of a herbicide, glyphosate on Roundup Ready crops, that is responsible for the growing epidemic of resistant weeds. This system has been presented to farmers as self-contained, two component, seed and Roundup, and that is the way it has been used. I am tired of people blaming farmers for this.

When a Federal district court judge reversed APHIS's deregulation of Roundup Ready alfalfa, he underscored APHIS's failure to examine glyphosate use. APHIS now gives purely pro forma attention to herbicide use in their regulatory reviews, and even this minimal treatment is grossly inadequate.

APHIS, for instance, dismissed analysis of herbicide use of Roundup Ready crops in the Roundup Ready draft and Environmental Impact Statement that relied on gold-standard data from its sister agency, the National Agricultural Statistic Service, and in its place it used bogus data from simulations conducted by pesticide industry-funded groups, like the National Center for Food and Agriculture Policy and PG Economics.

In other cases, USDA cited completely irrelevant data that was 10 years old or more, no relevance. APHIS also ignored research by scientists from USDA's Agricultural Research Service and others that point to potentially increased disease susceptibility in Roundup-treated, Roundup Ready crops. And, unfortunately, USDA does not require testing of Roundup Ready crops to which Roundup has been applied, which is the invariable practice of farmers. In view of the growing evidence of disease, possible disease susceptibility issues, that is inexcusable.

I would just like to say USDA should definitely follow the lead of the EPA. The successful insect resistant management program could be followed by USDA. And I don't buy Ms. Wright's protestations that USDA doesn't have authority. The noxious weed provisions of the Plant Protection Action clearly gives them authority to regulate practices that foster noxious weeds, and that is exactly what these Roundup Ready systems are.

Mr. KUCINICH. I thank the gentleman for his testimony. As I said, your entire testimony will be included in the record of this hearing. I am sure that we will get back to you with some questions. Thank you very much.

[The prepared statement of Mr. Freese follows:]

Testimony Before the Domestic Policy Subcommittee of the House Oversight and Government Reform Committee

by William Freese
Science Policy Analyst
Center for Food Safety

September 30, 2010

In 1997, just as Roundup Ready crops were being introduced, Monsanto scientists published a paper in which they presented all the many reasons weeds were NOT likely to evolve resistance to glyphosate, the active ingredient in Roundup [1]. Well, this prediction turned out to be wrong, disastrously wrong for a growing number of farmers. As discussed at Part 1 of this hearing in July, unregulated use of glyphosate-resistant crop systems has triggered an epidemic of glyphosate-resistant weeds infesting 10 million acres or more. It has also fostered sharp increases in herbicide use and greater use of soil eroding tillage operations, and is substantially raising weed control costs for ever more growers. Syngenta's Chuck Foresman projects a 40% annual increase in area with glyphosate-resistant weeds, which would infest 38 million acres, or one of every four row crop acres, just 3 years from now in 2013 [2].

Now Monsanto and other pesticide firms assure us that the solution to glyphosate-resistant weeds lies in a dizzying array of new crops resistant to older, more toxic herbicides like 2,4-D [3] and dicamba [4], and to multiple herbicides. DuPont envisions a single crop resistant to seven or more different classes of herbicides [5]. This is the major R&D focus of the industry, with hundreds of millions of dollars being invested [6], and resistance genes available for practically every major class of herbicide, including the notorious neurotoxin paraquat [7]. Nearly half of the genetically engineered (GE) crops pending deregulation at USDA are herbicide-resistant [8], and most will be offered in multiple herbicide-resistant (HR) cultivars.

We should not let ourselves be misled once again. These new HR crops are the wrong response to resistant weeds, for several reasons. First, they will substantially increase use of the associated herbicides, increasing our exposure to them in water and food. And as recently highlighted by the President's Cancer Panel, many pesticides are known or suspected

carcinogens that we should be reducing, not increasing, or exposure to [9]. Some pesticides, like 2,4-D, can also mimic human hormones, disrupting the body's intricate signaling system that plays such a crucial role in development, metabolism and reproduction. For instance, male pesticide applicators exposed to 2,4-D had lower sperm counts and more spermatic abnormalities than men not exposed to it. 2,4-D has also been shown to significantly depress levels of thyroid hormone, essential for normal development of the brain, in ewes treated with the chemical [10]. 2,4-D-resistant soybeans and corn break down 2,4-D into a still more toxic compound known as dichlorophenol, presenting food safety risks [11].

Second, HR crops facilitate ***mid-season*** use of herbicides that drift and volatilize to damage neighbors' crops. In some cases, farmers will purchase expensive HR seeds not because they want them, but to ***defend against*** drift from or misapplication by neighbors. Of course, even this is only possible if an appropriate HR cultivar of the pertinent crop is available. In either case, whether through crop damage or "defensive" purchase of expensive HR seed, the non-adopting farmer is incurring costs he should not have to bear.

Third, HR crops will accelerate the evolution of weeds resistant to HR crop-associated herbicides. Already, common waterhemp resistant to three and four classes of herbicides are rampant in Missouri and Illinois. Weeds can acquire resistance to herbicides one at a time, or to several at once via a mechanism known as metabolic degradation. The evolution of weed resistance to several herbicides simultaneously will be fostered by increased use of herbicide mixtures with multiple HR crops, a very troubling development. I would be happy to explain further why faith in multiple herbicide resistance as a "solution" to HR weeds is misplaced, and in fact will likely accelerate the evolution of weeds resistant to multiple herbicides.

The glyphosate-resistant weed epidemic is a symptom of regulatory breakdown, a devastating example of how thoroughly discoordinated the Coordinated Framework for Regulation of Biotechnology actually is. USDA's Animal and Plant Health Inspection Service (APHIS) regulates the HR crop, EPA regulates the associated herbicide(s). But NO ONE regulates the combination, the HR crop-herbicide system. And it is ***the system*** – the invariable use of glyphosate made possible and fostered by glyphosate-resistant seeds, for instance – that is

responsible for the growing epidemic of glyphosate-resistant (GR) weeds. This is clearly demonstrated by the near complete absence of GR weeds for the first 20+ years of glyphosate's use, and the explosion of weed resistance in the decade since the widespread adoption of Roundup Ready crop systems. We can anticipate similar issues with future HR crop systems unless serious regulatory action is taken.

When a federal district court judge reversed APHIS's deregulation of Roundup Ready (RR) alfalfa due to inadequate environmental assessment, he underscored APHIS's failure to examine glyphosate use linked to the RR crop, and the interrelated issue of resistant weeds, as a major failing [12]. Since that time, APHIS has given purely pro forma attention to herbicide use in association with glyphosate-resistant and other HR crops. And even this minimal treatment is grossly inadequate. In APHIS's draft environmental impact statement (EIS) on Roundup Ready alfalfa, for instance, it dismissed analysis of herbicide use with RR crops by an independent scientist that relied on gold-standard data from its sister agency, USDA's National Agricultural Statistics Service (NASS) [13], and mistakenly criticized these data as lacking in ways they aren't. Instead, APHIS relied on misinformation from bogus "simulation studies" conducted by pesticide-industry funded groups or contractors, such as the National Center for Food and Agriculture Policy (NCFAP) and PG Economics. In other cases, USDA cited pesticide usage data that were 10 or more years old, largely before Roundup Ready (RR) crops and the resistant weeds fostered by these crop systems drove substantial increases in herbicide use. I would be happy to provide more detail on these matters.

In still other cases, APHIS has ignored or dismissed research by scientists from another USDA sister agency, the Agricultural Research Service (ARS), that points to mineral deficiencies and increased disease susceptibility in Roundup-treated Roundup Ready crops [14], and in non-RR crops planted in the same field in subsequent seasons [15]. Interestingly, APHIS allows companies (e.g. Monsanto) submitting petitions for deregulation of glyphosate-resistant crops to submit the results of agronomic observation trials (to assess seedling vigor, growth habit, crop susceptibility to disease and insects, and similar features) that do NOT involve application of Roundup/glyphosate to the glyphosate-resistant crop. In view of the considerable and growing body of research by USDA ARS and other independent scientists alluded to above, this is

inexcusable. When a new GR crop is deregulated, the applicant has thus provided essentially no information on whether it is more prone to mineral deficiencies or fungal diseases than a conventional variety – despite peer-reviewed literature on similar GR crop systems suggesting that it very well may. A crop system that increases the disease susceptibility of a crop presents a potential plant pest risk that may require regulation under the Plant Protection Act.

In the programmatic EIS APHIS conducted for its GMO rules revision process that was completed in 2007, herbicide-resistant crops and weeds were almost completely ignored. Incredibly, the brief discussion of GR weeds referred to reports in Australia in the 1990s, and completely neglected to discuss the resistant weed epidemic triggered by RR crop systems in the U.S., much less any regulatory options for managing it.

USDA should follow the lead of the EPA, which has largely forestalled evolution of insect resistance to the insecticidal toxins in Bt crops through mandatory insect resistance management (IRM) plans. These plans have helped greatly to prevent the emergence of Bt toxin-resistant insect pests, despite serious compliance problems. Compliance deficits probably relate to the fact that IRM plans, though mandatory, are largely administered by the biotech-seed companies themselves. One example is Monsanto's illegal distribution of Bt cotton seeds in Texas over the five years from 2002 to 2007 without informing farmers of IRM planting restrictions in grower guides, for which EPA levied a $2.5 million fine on the company [16]. Thus, more direct involvement and oversight by EPA would be desirable.

EPA determined that because the insecticidal protein was incorporated in and inseparable from the Bt plant's tissues, its regulatory jurisdiction extended to the Bt plant. Based on its assessment that Bt insecticidal toxins are less toxic than conventional chemical insecticides, and that selection pressure for evolution of Bt toxin-resistant insects would be enormous, and thus rapidly degrade the efficacy of these compounds through resistance, EPA determined that mandatory resistance management was called for – to preserve the efficacy of these compounds as a public good.

Very similar considerations apply to glyphosate and glyphosate-resistant crops. The mere fact

that the GR plant and glyphosate are not physically joined as Bt toxins are in Bt crop tissues matters little in practical terms if indeed the two are invariably used together, as they are, by design. And since glyphosate is generally regarded as less toxic than most herbicides, it would be beneficial to preserve its efficacy. We should note, though, that many scientists have found that certain supposedly "inert" ingredients added to Roundup formulations to increase the efficacy of glyphosate are more toxic than glyphosate itself. One such "inert" ingredient in particular, polyethoxylated tallowamine (POEA), has long been implicated in causing high mortality to populations of frogs exposed to Roundup formulations containing it at field-relevant concentrations [17]. (To its credit, Lisa Jackson's EPA is taking initial steps towards improved regulation of these often toxic "inert" ingredients.)

However the science eventually plays out on the toxicity/safety of glyphosate and its various formulations, it would be beneficial to preserve its efficacy, and that means checking the GR weed epidemic. Roundup Ready crop systems have proven to be wonderfully adapted to breed rapid evolution of GR weeds. Such weeds, once emerged, can spread to infest the fields of other growers, including those who do not use glyphosate-resistant crops at all. (The windborne seed of horseweed can travel for miles on the wind [18], and it is perhaps not a coincidence that GR horseweed is the most prevalent of GR weeds, infesting at last count up to 6.3 million acres in the U.S. [19]). Such a grower (say of wheat) may well use glyphosate as a burndown herbicide. Single season burndown use of glyphosate is much less likely to foster evolution of GR weeds than the two and three in-crop applications that are becoming ever more common for Roundup Ready growers. A wheat grower whose fields are infested with GR weeds in this manner, through no fault of his own, would have to apply more toxic herbicides like 2,4-D instead of (or in addition to) glyphosate, incurring both added cost and potential harm to health.

USDA has the authority to regulate HR crops for their clear propensity to foster rapid evolution of HR weeds under the noxious weed provisions of the Plant Protection Act, as well as the general provisions charging APHIS with protection of the "interests of agriculture." When one considers the huge costs imposed on cotton growers by glyphosate-resistant Palmer amaranth and horseweed, regulation becomes not just possible, but an urgent necessity. According to University of Georgia's Brad Haire, speaking of glyphosate-resistant Palmer amaranth: "We're

talking survival, at least economically speaking, in some areas, because some growers aren't going to survive this" [20]. Eminent weed scientist Alan York has a similar take, once comparing glyphosate-resistant Palmer amaranth to the boll weevil in terms of the threat it poses to the U.S. cotton industry [21]. The boll weevil devastated cotton growers throughout the South, making it impossible to grow for many years in some areas, and necessitated massive campaigns for its eradication. By one account, the boll weevil cost the cotton industy $46 billion dollars over the past century [22]. In the face of costs and risks from GR weeds that are even a fraction of this magnitude, continued inaction by USDA is irresponsible.

CFS has the following recommendations.

1) USDA should refrain from deregulation of any new HR crop, particularly Roundup Ready alfalfa and Roundup Ready sugar beets, unless or until:
   a. Weed resistance management plans, and
   b. Protection plans for those farmers who choose not to adopt the HR crop;
   are made mandatory conditions for commercial planting. Good resistance management plans will take study and work, and input from growers as well as extension agents, independent scientists and the EPA.

2) Such management plans would best incorporate some prohibition on continual, year-in, year-out planting of an HR crop in order to lessen selection pressure for evolution of resistant weeds from continual use of the associated herbicides(s). Such management plans should be developed for existing GR crops as well. This would be the temporal equivalent to the spatial refugia required (or once required) by EPA for IRM. USDA should consult with EPA in formulating such plans.

3) USDA should promote integrated weed management practices ***that prioritize non-chemical modes of weed control, such as cover crops,*** and do this at every level: research, stronger IWM curricula at land grants, demonstration plots, training of extension agents and farmers, etc. Winter cover crops such as cereal rye, hairy vetch and red clover are planted in the fall after the main crop's harvest, grow in the fall and

next spring, and when killed prior to spring planting provide physical suppression of weeds in the following main crop. Cover crops provide multiple additional benefits as well, including uptake of excess nitrogen and phosphorus from fertilizer application (reducing adverse nutrient loading of water bodies from runoff) and inhibition of soil erosion during snow thaw in the spring. Weed scientists have specifically recommended increased use of cover crops to suppress glyphosate-resistant weeds. Such promotion of IWM practices could be funded by USDA's National Institute of Food and Agriculture, and perhaps also by an HR seed fee that is collected from each pesticide-biotech firm for each acre of HR seed or HR trait acre that is sold. USDA should also fund active and comprehensive monitoring of herbicide-resistant weeds led by independent land grant scientists, as recently recommended by the Government Accountability Office, given the inadequacies of the current system, funded largely by the pesticide industry.

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Mr. KUCINICH. Mr. Vroom.

STATEMENT OF JAY VROOM

Mr. VROOM. Thank you, Chairman Kucinich and Congresswoman Watson, for allowing me to come and provide testimony today on behalf of the crop protection industry and CropLife America. Thank you for introducing me earlier.

In addition to my role as CEO of our trade association, I also have an Illinois farm background and happen to still own the family farm that I was reared on.

I happen to have been in Illinois twice in the last 6 weeks. Six weeks ago I stopped to take a look at one of the fields that is now being operated by my cousin. It was planted this year in Roundup Ready Soybeans. It was planted as a no-till crop, and Mr. Chairman, I would love to share this photograph. There are three of them here. I am most proud of this particular view, because it shows this field in the direction in which a terrace that my father installed as a charter member of our Bureau County, IL, soil and water conservation district, one of the first terraces installed in the country, to provide then the cutting-edge technology for soil conservation at that time.

I remember as a youth hand-weeding and hand-cultivating with mechanical means fields of soybeans and other crops on this very field, and we were not able to control the soil erosion as we can today with the Roundup Ready technology. If I can pass this up and maybe ask your staff to share that with you.

Mr. KUCINICH. We will include it in the record. Without objection, so ordered.

[The information referred to follows:]







Mr. VROOM. Thank you.

So conservation tillage is an important component of the introduction of biotechnology.

I also have a report by our Crop Protection Research Institute that illustrates on page 2 a graph of introduction of modern biotechnology and then the takeoff of the adoption of conservation tillage in this country. It has made a meaningful difference, and I believe there are clear USDA statistics to that effect.

Mr. KUCINICH. Without objection, that will be included in the record of the hearing.

[The information referred to follows:]

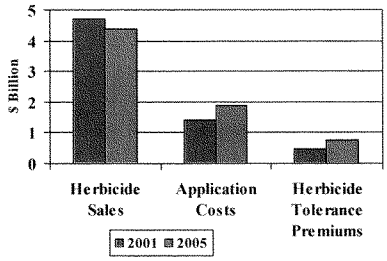
CropLife Foundation
Crop Protection Research Institute

The Value of Herbicides in U.S. Crop Production: 2005 Update

Executive Summary

Herbicides are chemical pesticides that kill weeds. U.S. farmers have sprayed herbicides on nearly 90% of the nation's cropland acreage for the past 30 years.

The value of the use of herbicides in 2005 is estimated to have been $16 billion in increased crop yields and $10 billion in reduced weed control costs.



The use of herbicides greatly reduces the need for fuel and laborers on U.S. farms. If farmers did not use herbicides, the alternatives for weed control would be increased mechanical cultivation and increased hand labor to pull weeds. The need for fuel would be 337 million gallons higher, since twice as many cultivation trips would be needed to replace herbicide spray trips and cultivators use four times more fuel per trip than herbicide sprayers. A minimum of 1.1 billion hours of hand labor would be required at peak season for hand weeding, necessitating the employment of 7 million more agricultural workers. Even with the increased cultivation and hand weeding, crop yields would be 20% lower. Approximately 70 million workers would be needed to prevent any yield loss without herbicides.

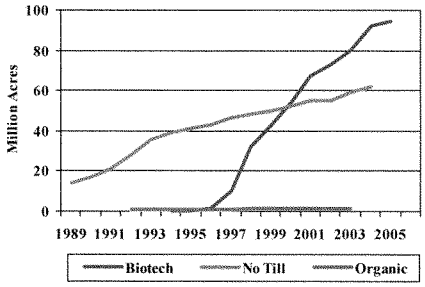
The largest production loss would be in corn, with a reduction of 2.7 billion bushels. Corn is the main feedstock for U.S. ethanol production, a major alternative being developed to reduce dependence on oil. The corn production loss due to the non-use of herbicides is equivalent to 7.3 billion gallons of ethanol, which is equal to the entire projected capacity of U.S. ethanol production by 2010.

Without herbicides, U.S. growers would have to abandon no-till production practices, which are effective and popular techniques for reducing soil erosion. Without tillage, growers kill weeds with herbicides. If U.S. growers stopped using herbicides and resumed tillage on the 62 million acres that were not tilled in 2005, soil erosion would be 356 billion pounds higher than it is today. Soil erosion deposits sediments in streams and rivers resulting in downstream damages. The damage resulting from increased soil erosion due to farming without herbicides is estimated at $1.4 billion.

Value of Herbicides in U.S. Crop Production: 2005	
Total Acres Treated with Herbicides	215 million
Current Herbicide Cost to Growers	$7.1 billion
Herbicide Non-Use Cost Increase	$9.7 billion
Herbicide Non-Use Yield Loss (*Volume*)	295.7 billion pounds
Herbicide Non-Use Yield Loss (*Value*)	$16.3 billion
Herbicide Non-Use Labor	+1.1 billion hours
Herbicide Non-Use Erosion	+356 billion pounds
Herbicide Non-Use Fuel Consumption	+337 million gallons
Herbicide Non-Use Net Income Impact	-$26.0 billion

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This report for 2005 is an update of a previously issued report for 2001. The same methodology was used in both reports, which makes it possible to report on fluctuations in the herbicide market and changes in the benefits of herbicides. Due to significant price decreases, U.S. farm expenditures for herbicides declined by $300 million between 2001 and 2005. The price decline for herbicides was outweighed by increases in the costs of applying herbicides due to higher labor and fuel costs (+$500 million) and increases in the premium prices paid for biotech herbicide-tolerant seed (+$312 million). Thus, the total cost of herbicides and their application increased by $512 million between 2001 and 2005.



Increased fuel and labor costs, however, also made the costs of alternatives to herbicides higher. The aggregate cost of cultivation and hand weeding as replacements for herbicides increased from $14.3 billion in 2001 to $16.8 billion in 2005, resulting in a net increase in weed control costs without herbicides from $7.7 billion in 2001 to $10 billion in 2005. The value of the crops also increased significantly between 2001 and 2005, which means the 20% loss in production without herbicides is worth more in 2005 ($16 billion) than in 2001 ($13 billion). Overall, the value of herbicides increased from $21 billion in 2001 to $26 billion in 2005.

Three trends that occurred in crop production and weed control between 2001 and 2005 are noteworthy, especially those relating to no-till, biotech, and organic crop production. Two of these practices are dependent on herbicides and one is not. The number of no-till acres on which herbicides substitute for tillage increased from 52 million acres to 62 million acres. The number of biotech herbicide tolerant acres where herbicides are used with crops that have been genetically-engineered for tolerance increased from 66 million acres to 94 million acres. Meanwhile, the number of cropland acres grown according to organic standards where herbicides are not used increased by 100,000 acres to 1.4 million. Organic farmers substitute labor and tillage for herbicides, which is very costly. The problem of controlling weeds without herbicides has been cited numerous times as the single largest obstacle that organic growers encounter. The following quotation from Earthbound Farms (the largest organic producer in North America) underscores the expense of doing without herbicides:

> *Controlling weeds without herbicides takes a lot of time and is very costly for us. We do all our weeding by tractor or by hand, which is very labor intensive. Conventional farmers spend only about $50 an acre on herbicides that knock out every weed in sight. Organic farmers may have to spend up to $1,000 an acre to keep weeds under control.*

There is not likely to be a vast expansion in domestic organic acreage due to the high cost of labor in the U.S. in comparison to many developing countries.

The full report, *The Value of Herbicides in U.S. Crop Production: 2005 Update*, including state and crop specific data, is available on the Crop Protection Research Institute's web site at: http://www.croplifefoundation.org/cpri_benefits_herbicides.htm. For more information, please contact the authors: Leonard Gianessi at 202-872-3865 or lgianessi@croplifefoundation.org or Nathan Reigner at 202-872-3866 or nreigner@croplifefoundation.org.

Mr. VROOM. Thank you.

My experience, and I just talked to my cousin who was combining soybeans this morning, he assured me that he was aware of weed resistance and he has taken steps to manage it on this particular field, and we know that we don't have the most severe weed-resistance problems with regard to glyphosate situations, as are apparent in some of those 11 million acres that you refer to.

Our industry, along with USDA—and unfortunately Ms. Wright probably didn't have adequate time or background to explain to you the full resources the USDA brings to bear with regard to helping farmers manage weed resistance in both biotechnology crops and elsewhere. Extension, our industry scientists, crop consultants that are private individuals, crop input retailers, all have a stake in all of this and we have a marvelous system to help farmers manage these issues. But we do appreciate the fact that you have an interest in examining the regulatory authority of the agencies that are charged with overseeing these technologies, and we look forward to working with you as you give consideration to ways to have oversight and consideration of these matters.

Last, I would just tell you that our industry has formed a herbicide resistance action committee. It is a global entity that CropLife and our partner associations around the world are involved with, and it provides a mechanism for the common research that herbicide companies engage in with regard to helping to stay ahead of the curve and ensure that we can manage herbicide resistance in both biotechnology-enhanced crops and conventional crops as well.

So we believe that we do have a system in place that allows us to continue to manage these issues. We understand the particular media attention that has been given to herbicide resistance in biotechnology crops, but we believe that we have an adequate system, and we appreciate the attention that you will continue to provide to this issue.

Mr. KUCINICH. Thank you very much, Mr. Vroom.

[The prepared statement of Mr. Vroom follows:]

Testimony of Jay Vroom
President and CEO
CropLife America

Before the Domestic Policy Subcommittee,
House Oversight and Government Reform Committee

"Are Superweeds and Outgrowth of USDA Biotech Policy"

September 30, 2010

Thank you, Chairman Kucinich and Ranking Member Jordan, for the opportunity to address the Subcommittee on behalf of CropLife America and its members, as well as their customers the American farmers. CropLife America is the leading trade association representing the U.S. crop protection industry and our members supply virtually all of the crop protection products used by American farmers. CropLife America's member companies, and members of our counterpart association at RISE[1], proudly discover, manufacture, register and distribute crop protection products for American agriculture, and specialty use products outside of agriculture, such as those used for public health protection and commercial pest management inside of homes and commercial buildings.

CropLife America members work with farmers, ranchers and growers everyday to ensure that crop protection tools are registered properly and used correctly. As a matter of fact, America's abundant, affordable food supply depends on the availability of safe, effective crop protection products. Careful use of crop protection products contributes substantially to production of U.S. farm exports valued at some $100 billion per year. CropLife America members support modern agriculture by looking forward: each year the agrochemical industry spends hundreds of millions of dollars on research and development, with much of that investment going into producing data that meet or exceed the Environmental Protection Agency's (EPA) information requirements and requests for pesticides.

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[1] Responsible Industry for a Sound Environment (RISE) – www.pestfacts.org

Three major points are essential to understanding weed resistance to herbicides and the need for best management practices to minimize the potential for resistance development:

- First, herbicide resistance occurs naturally, and best management practices need to be applied in ensuring that resistance development is avoided or delayed.
- Secondly, the market can and will facilitate the development of solutions to combat the issue of weed resistance in crop production to ensure production of safe, affordable, and plentiful food.
- Third, the current regulatory framework for herbicides is robust.

Weeds, insects and fungi readily adapt genetically to their environments. Pesticides and other pest control technologies, used over widespread areas, will control many target pests, but some pests may have a genetic advantage and survive. The survivors, if not removed from fields physically or with an alternative chemical control option, will grow and become more prominent in the local environment. Weed adaptation has been happening as long as man has tried to grow crops and is not unique to the use of chemical control or adoption of biotech crops. Under a regimen of physical control, weeds might become physically harder to distinguish or more difficult to remove. While 'superweeds' might be a catchy moniker, there is nothing particularly super about the weeds that have developed resistance to any particular herbicide. Resistance of a particular weed species to a particular herbicide has arisen multiple times over the past several decades. The problems have been overcome through adjustments to the use of the specific herbicides, and through availability and use of additional herbicides and weed control strategies, all acting by different mechanisms, so that no one weed species or variety can escape all of the control approaches.

To avoid the onset of resistance growers need to be aware of and adopt best management practices (BMPs). Information regarding BMPs and integrated weed management is available from multiple reliable sources. Growers who ignore that information do so at their peril, with potentially serious economic consequences. Adoption of biotechnology hasn't caused the rapid onset of resistance in weed species; appropriate use of all technologies will reduce its impact.

The market can and will facilitate the development of solutions to the issue of weed resistance in crop production to ensure production of safe, affordable and plentiful food. Farming is a long-term investment, and growers will adapt their operations to succeed. They need the flexibility to manage their farm operations for the current season and for the future. That flexibility requires access to the tools that enable them to take care of their business interests and sufficient latitude in terms of how and when they are used. Growers are in the best position to know their fields, the weeds growing in them, and how to best manage their farm inputs. Such knowledge will enable them to make the best decisions on what tools to use, including crop protection products and biotech crop seed, considering the economics and their future management plans.

Weed control options will continue to be developed. Crop protection is a competitive business. If a weakness in a particular weed control option emerges, there will be other new or existing technologies that will seek to fill that void. The market favors maximization of the tools currently available. The development of new herbicides is an involved and expensive process. To make that investment worthwhile requires that the useful life of a product will be extended as long as possible with available means. Some recent marketing programs have included manufacturer rebates for use of competitive products in combination with a company's product, in order to stem the onset of resistance. This is one example of how the market addresses the issue.

Regulation of pesticides, including herbicides, is science-based, stringent, thorough and robust. The approval process and use of pesticides are overseen by the Environmental Protection Agency (EPA) through implementation of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Development and registration of a new pesticide active ingredient takes 8 to 10 years, costs over 200 million dollars, and requires at least 120 scientific studies, conducted at the manufacturer's expense and thoroughly reviewed by EPA. EPA must approve the product label before it grants a "registration" for sale and use of the product. The label contains the necessary instructions and precautions to use the product safely and effectively. When used according to the label, registered pesticides will not harm humans, animals or the environment. EPA continues to monitor use of the pesticide in the marketplace. If problems in product efficacy are discovered by EPA or the registrant or users, adjustments are made as necessary to the label

instructions to make sure the product can continue to be used safely and effectively. The changes may be initiated either by EPA or the manufacturer, but must be approved by EPA.

I appreciate the opportunity to appear before the Subcommittee today to discuss the important issue of resistance management on behalf of the chemical crop protection industry. We remain committed to continuing to work with the Congress, our regulator and our end-users who use our technology to produce our nation's safe, affordable and abundant food supply. I look forward to answering any questions you may have regarding my testimony.

Mr. KUCINICH. I just want to assure you that we provided Ms. Wright with as much time as she needs to be able to answer this committee's questions, and we will continue to do that.

Let's go to questions of this second panel.

Mr. Miller, with Monsanto's 100 percent focus, as you have said, on agriculture, I am wondering who is responsible for the proliferation of weeds and weed species that have become Roundup-resistant since the introduction of Roundup Ready crop systems?

Mr. MILLER. Thank you, Mr. Chairman. As I mentioned earlier, if our farmers are not successful, we are not successful, and we take this matter very seriously.

I would say herbicide-tolerant weeds is not a new thing. It is something we have had to manage in the industry as well as with university weed scientists and farmers in how they run their operations on their farm. So we invest a lot in the science of weed resistance and understanding that and providing technical solutions to growers along with others. That is really our focus.

Mr. KUCINICH. I don't know if you have testified before a congressional committee, and all committees are different.

Mr. MILLER. No, sir.

Mr. KUCINICH. I am the kind of chairman that when I ask a question, I would like to get a direct answer.

Would you tell me who is responsible for the proliferation of weeds and weed species that have become Roundup-resistant since the introduction of Roundup Ready crop systems?

Mr. MILLER. I think weeds that are resistant to glyphosate are the responsibility of industry, government, weed sciences, as well as farmers, to properly steward the product.

Mr. KUCINICH. So industry—you are part of the industry with Monsanto. The USDA is part of that system. There is a responsibility there. There is a whole feedback loop here, you are saying; right?

Mr. MILLER. I think there is a feedback loop, but this is a herbicide issue, and I believe herbicides are regulated under the Environmental Protection Agency.

Mr. KUCINICH. It is encouraging that you have stated that industry has a responsibility here. But you also stated that government has a responsibility as a regulatory authority, did you not?

Mr. MILLER. Mr. Chairman, I believe that our regulatory agencies have clear responsibilities to demonstrate and prove the safety in use of these products.

Mr. KUCINICH. Thank you. Let me direct your attention to this ad circulated before 2005. This is Monsanto, Mr. Miller, in this ad, telling farmers to use more and more Roundup and to use it exclusively to control weeds. That was just 5 years ago. And it was also 5 years after Roundup-resistant horseweed was discovered in Roundup Ready crop yields in Delaware.

Mr. Miller, help us out here. Isn't it true if farmers followed Monsanto's advice conveyed in this ad, that they would have Roundup-resistant weeds in their fields today?

Mr. MILLER. Mr. Chairman, weed resistance is caused by many factors. Prior to 2005, and many systems that we developed and co-developed with the university weed science academics and the Weed Science Society of America—and, by the way, I believe one

of those academics was actually referenced in that ad just reflecting on a picture I saw—the recommendation was that glyphosate had a low probability of developing resistance, and our recommendation was to utilize that in the system.

But in cases where we have begun to discover there are resistant weeds, we have done a lot of training, education with growers, retailers, and other in the industry to recommend multiple modes of actions into our cropping systems.

Mr. KUCINICH. I am going to ask staff to copy this and give you a copy. Have you read this? Just look at it. I'm not trying to trap you here, because I believe in having a conversation. It says no benefit in rotating glyphosate. No benefit.

Can you explain that to me in light of what you said a moment ago? Take your time. When you are ready to answer, go ahead. If you want to rephrase anything for the record, you can do that, too.

Mr. MILLER. Actually, I would like to read the recommendation as stated by Monsanto in this particular article.

In many Midwest cropping systems, agronomic conditions and cultural practice are conducive to preemergent application, an herbicide that is not glyphosate, so one mode of action, followed by Roundup agriculture herbicides, or a tank mix of residual, two different modes of action, agricultural herbicide before weeds exceed 4 inches.

So this particular ad does actually steward two growers, and I am responding to the title, "No Benefit from Rotating Glyphosate," was the fact that you use multiple modes of action in your system, and if you use a Roundup Ready crop in the same field the next year, and you steward it properly by using multiple modes of action, there is no need to change your overall cropping system.

Mr. KUCINICH. This is your ad. It says, no benefit in rotating glyphosate, as you just read.

Now, I showed the same ad and asked the same question to a prominent weed scientist who testified at our previous hearing. I am sure that somebody in your organization read that testimony. He was the author of the weed chapter of the National Research Council's report published in April.

Do you want to guess what his response was to the question of whether farmers would have Roundup-resistant weeds in their fields today if they followed the advice that was conveyed in Monsanto's ads? What do you think his answer was?

Mr. MILLER. Chairman Kucinich, I wouldn't want to speculate on that.

Mr. KUCINICH. OK. That is fine. It is recommended reading for you. His answer was "yes."

Mr. Miller, why was the discovery of Roundup-resistant horseweed as early as the year 2000 not sufficient evidence of Roundup resistance in weeds to move Monsanto to change its advice to farmers?

Mr. MILLER. Congressman, first of all, I will go back to if our growers are not successful, we are not successful. So as we actually had the evidence of the first resistant weeds, we actually enabled university research, our own research, to understand the mechanism of that resistance.

The second thing that we did was enlisted those regional university extension agents to help us develop what the recommendation for the grower was in order to keep their farming operations successful. Once we had that identified, we actually went out and did significant training with producers, often recommending our competitor's product as part of the solution to ensure that the farmer has a weed-free field.

Mr. KUCINICH. Let me just share something with you. About 5 hours ago, I was in a full committee hearing with Johnson & Johnson looking at how they let two different products enter the market, one of which had potential serious health consequences for consumers. And one of these drugs, they sent in phantom purchasers to get the drug back. There was active concealment going on.

The thing that strikes me that you said about if your customers are not successful, you are not successful. You said that earlier in your testimony. I actually wrote it down here. If farmers don't succeed, Monsanto does not succeed. It is eerily similar almost to the words except changing "Johnson & Johnson" to "Monsanto" to the testimony of the CEO of Johnson & Johnson. That is the reason I am calling it to your attention. I don't question your background. You have a tremendous background and you are certainly qualified to testify before this subcommittee. There is no question about that. You represent Monsanto well.

The question I have is the aspirational expressions that you make on behalf of Monsanto do not square with the experiential elements of the use of this crop. That is kind of where we are going with this. I am not condemning you; I just want to say that there is some difficulty in squaring this.

Now, Mr. Freese, is it true that Roundup-resistant weeds was a development that took everyone, including Monsanto, by surprise? Or was it a foreseen danger?

Mr. FREESE. I think it was mixed. I know there were some weed scientists who thought there wouldn't be resistance evolving, but others predicted it.

Mr. KUCINICH. Some were surprised?

Mr. FREESE. Yes.

Mr. KUCINICH. What about you?

Mr. FREESE. I wasn't following the issue at the time.

Mr. KUCINICH. But you have a 1980 report; isn't that right?

Mr. FREESE. A 1990 report, yes, by some colleagues in the public interest community called "Biotechnologies: Bitter Harvest." It is a very searching and comprehensive report on what at that time was still an experimental technology. 1990, this was 6 years before the introduction of the first Roundup Ready crop—in this report the scientists clearly see huge potential for development of herbicide-resistant weeds, and particularly with this technology.

There was a 1996 report by Consumers Union, another consumer group.

Mr. KUCINICH. So you are saying that scientists did see the potential for herbicide-resistant weeds. Which scientists are you talking about?

Mr. FREESE. This report was written by Dr. Rebecca Goldberg with Environmental Defense Fund; and Jane Rissler, who is now

with Union of Concerned Scientists; and Hope Shand and Chuck Hassebrook.

Mr. KUCINICH. What year was that?

Mr. FREESE. 1990.

Mr. KUCINICH. Mr. Miller, you have been with Monsanto since 1994, right?

Mr. MILLER. That is correct.

Mr. KUCINICH. I actually took notes during your testimony, and you said in your testimony that Monsanto has 500 scientists who work for the company. Did you say that?

Mr. MILLER. Actually, sir, my statement was that in my regulatory group there are 500 scientists. There are over a couple of thousand scientists in our company.

Mr. KUCINICH. That is even more impressive. A couple thousand scientists. Do you have any knowledge within the sphere of your activities in the regulatory group of any reports that were brought to you expressing concerns about herbicide-resistant crops?

Mr. MILLER. I was not in that responsibility at that time. But I can say——

Mr. KUCINICH. When did you come into that responsibility?

Mr. MILLER. Just in the last 6 months, sir. But I have been in the company 16 years as a researcher. I can share with you that I think it is even documented in literature that with the Roundup or glyphosate tolerance, we stated there was a possibility. We said it was a low probability.

And I would say anytime we develop any of our products, as I mentioned earlier, including with Mr. Smith here, before we develop them, we actually create forums to understand the data that is out there and the concerns that exist, and take that into consideration as we develop our safe products.

Mr. KUCINICH. What I would like to do, and I want to direct the subcommittee staff here to work with Mr. Miller in gaining access to the studies that were done by the scientists at Monsanto with respect to herbicide-resistant weeds, because what we can do here is to be able to identify the progress that has been made through this scientific research with the 500 scientists who are working for you and perhaps thousands of scientists who are working with Monsanto.

So we will produce from this hearing a followup request for documents so that we can enable a better understanding of Monsanto's awareness of this. I would appreciate your cooperation.

Mr. MILLER. Mr. Chairman, I will be happy to work with you on that request.

Ms. WATSON. Mr. Chairman, can you yield just 2 minutes to me? I have another subcommittee hearing.

Mr. KUCINICH. I am pleased to yield to the gentlelady at this moment. I was going to yield 10 minutes to you. If you need 10 minutes, you can have it now.

Ms. WATSON. Thank you. I won't use all of that time. I am very interested in this subject matter, because just recently they announced that there is a new salmon that is going to be on the market that has been, shall I say, biologically bred to grow larger, and you might recall some of the advertisements in the last few days.

We are questioning whether that will have an impact on humans once they consume that salmon. And so I was listening very closely to see if Monsanto or other companies like you test the environmental impact of these new—what you are working with is an herbicide—but do you test first to see what the impact will be on the environment. Or does it grow?

The chair is asking for you to kind of document what was done prior to putting it on the market, and I am wondering how far do you go putting these products out there before you test their effect on the environment?

Mr. MILLER. Would you like me to answer that?

Ms. WATSON. Yes.

Mr. MILLER. OK. You know, I am very proud of the process that we use both to validate the value that we bring to growers, as well as the safety of our products. As you know, the products that we have put out on the market , if it is a chemistry, it is EPA. Biotech, it could be EPA, USDA, FDA. All of those go through thorough health and safety assessments both internally in our organization as well as with those agencies.

Often we have other third parties that look into that, because at the end of the day, we want to ensure the health and safety, and we believe that system has worked extremely well.

Ms. WATSON. What do you feel you have to do now in light of this, the findings that this superweed is so strong that it doesn't react to whatever you have out there to try to kill it? It is going to have an impact, and it is going to have a financial impact certainly on the farmers and all.

And so what do you see that needs to be done? We are the subcommittee of oversight. What is it that we can do within this process to guarantee that people won't be harmed, crops won't be harmed? What needs to be done? What are we missing?

Mr. MILLER. Chairman Watson, I am not sure I can address the question of what we are missing, but I can address what we are doing. I think this is being taken very seriously by Monsanto, as well as other technology providers in the industry. I think it is being taken extremely seriously by weed scientists. And as was mentioned by Jay earlier, our growers take this very seriously, even before they have weed-resistance issues. What we are doing about it, we have invested well over $30 million in just the last 5 years.

Mr. KUCINICH. If the gentleman would suspend. Ms. Wright, I just want to put it on the record that Ms. Wright did stay for most of the testimony because that doesn't always happen, and I want to thank you for your presence here and for listening to the witnesses' testimony and questions. Thank you very much. I just wanted to put that on the record.

If you are ready to continue, you may. Thank you.

Mr. MILLER. Yes. So we are putting significant research, as well as working with those local academics to help come up with best recommendation for farmers.

Two things that I want to bring out. There are glyphosate-resistant weeds, but there are still greater than 290 weeds that do not have resistance, so this is still a hugely available tool to growers, and they acknowledge that every time I go out and visit with them.

I am not going to diminish the fact that if one of the weeds is resistant to glyphosate, that there needs to be a control option provided for that grower, and we actually have spent a lot of time, even with the ad that was shown earlier, working on that particular species of weed. There are control options available on the market, and we are helping growers be trained on how to use that in their agricultural systems.

Ms. WATSON. I am really concerned about the consumer side of all of these new products that are out there, and so we are going back and the chair is asking that we have some documentation so that we can guarantee that we who have the oversight have done all we can to ensure that these products will not have a negative effect on whatever it is, and on consumers. So we are just probing right now to see what our responsibilities are.

And if you are looking at evaluating the environmental impacts of your product, I want to say thank you so much. That is what I would like to know. And I am sure that the chair has also asked for that information.

With that, I will wait to see it. As we probe in this area, Mr. Chairman, I want to be a partner with you.

I am really concerned about that new—does anybody remember seeing the information on television? If so, put your hand up. I want to know about this salmon that is going to be three or four times the size of any normally grown salmon. If we are to consume it, what is the impact going to be on our digestive systems with this larger salmon?

So in all good faith, we are just asking you to let us know what we need to look at so we can protect the consumers.

Thank you very much.

Mr. KUCINICH. I thank the gentlewoman for her questions. The subcommittee is also looking at the issues with respect to genetically engineered salmon.

I want to say, when the gentlelady asked the question, What are we missing, she was actually inviting Mr. Miller to help us in our probe here. But I would say this; that we look forward to cooperating with you, that cooperation through information that brings us to a level of comfort that the public interest is being protected. And in pursuit of the public interest, we try not to miss too much.

Mr. Miller, you have heard testimony today about concerns that your dicamba/Roundup-tolerant soybean will cause collateral injury to fruit and vegetable farmers, and I would add, even backyard gardeners. That is essentially what Mr. Smith was testifying to. Your testimony, in fact, acknowledges concerns.

Now, in the event that an injury should materialize, apropos of a question Mr. Smith raised, who would be liable for the economic costs to the affected farmers? Would it be Monsanto or another party?

Mr. MILLER. Mr. Chairman, you know, I am not an attorney.

Mr. KUCINICH. I am not either. I just play one on TV.

Mr. MILLER. I don't believe I can answer that. We would be happy to followup with you later at the appropriate time when we have that information.

Mr. KUCINICH. I will accept you are not an attorney and you don't want to answer a question that gets you, excuse the expres-

sion, into the weeds about the legal implications of this policy. But I would say that we would seek to entertain that discussion with Monsanto attorneys, because this is one of the questions that is being raised here. You have a product, if it has some adverse effect on certain people, there are some questions of liability.

I am not asking you to accept liability here. I know what your limitations are as a witness at this moment. You made that clear.

But let me ask you this: Do you think it is correct to classify the injury fruit and vegetable farmers fear from the use of the dicamba soybean system as an indirect cost of the development of Roundup resistance in weeds?

Mr. MILLER. Mr. Chairman, I am not sure that I follow your question. I would appreciate if you could restate it.

Mr. KUCINICH. Well, you have Roundup resistance in weeds that is showing up. Farmers are concerned, and some farmers have expressed that there has been an injury to their fruits and vegetables. You have sold this dicamba soybean system. If the farmers are experiencing this loss, isn't that loss essentially an off-loading of expense, an indirect cost of the development of Roundup resistance in weeds?

Mr. MILLER. You know, we are 5 years away from introducing dicamba/Roundup Ready soybeans into the market. So as we bring these forward—and it takes us well over a decade from the time we begin to develop these products until we launch it—5 years before the launch, we actually set up a dicamba grower or dicamba advisory council, including many of the producers in the fruit, vineyard, and tomato industry.

And by the way, as Monsanto, we are one of the largest vegetable seed producers in the world. Tomato customers in that business are some of our biggest customers. And as I mentioned earlier, we care about our customers' success.

Our focus is to continue to bring weed-free cropping systems to our producers in corn, soybean, and cotton, as well as serve the interest of those fruit and vegetable producers. We have a significant amount of research going on, with their input, to ensure when that product comes on the market it is successfully implemented.

Mr. KUCINICH. Do you have legal counsel here with you?

Mr. MILLER. Yes, I do.

Mr. KUCINICH. Would counsel identify himself, please?

Mr. SOPKO. John Sopko of Akin Gump.

Mr. KUCINICH. OK. Actually, I know you gave an answer. You didn't answer the question; but if I pressed you to answer the question, I know counsel would advise you not to, so I will move on.

Mr. Freese, can you answer the question I asked about do you think it is correct to classify the injury fruit and vegetable farmers fear from the use of the dicamba soybean system as an indirect cost of the development of Roundup resistance in weeds?

Mr. FREESE. I think that is very good way to describe it. The way that the Roundup Ready crop system is used and is meant to be used, I would say it has led to some pretty massive weed resistance. Unfortunately, the way we approach weeds in this country is so completely focused, so completely focused on using pesticides, that a new herbicide-resistant crop, resistance to different herbicides, seems to be the only thing that a lot of our companies and

even the USDA takes seriously. In fact, there are many very viable, nonchemical ways to control weeds.

Mr. KUCINICH. I am going to go back to Mr. Smith here, because you are in touch with a base of people about these products. You have testified, and I am quoting from your testimony, "The widespread use of dicamba is incompatible with Midwestern agriculture."

Mr. SMITH. Yes, sir.

Mr. KUCINICH. I am from Ohio. I hear that. How significant is the risk of injury to fruit and vegetable farmers and processors from planting the dicamba soybean in Indiana farm fields, and do you have any estimate of potential cost?

Mr. SMITH. We are working on providing an estimate of that through a study with Purdue University at this time.

Mr. KUCINICH. Would you produce that to the subcommittee when that is done?

Mr. SMITH. Yes.

Mr. KUCINICH. You testified, "Increased dicamba usage, made possible through the introduction of dicamba-tolerant soybeans, is poor public policy and shouldn't be allowed."

Is there is a technological fix to the collateral harm you foresee occurring, such as having Monsanto develop dicamba-resistant fruit trees, melons, peas and tomatoes; is that the path we should take?

Mr. SMITH. From a consumer standpoint, that is a path we cannot take.

Mr. KUCINICH. Why?

Mr. SMITH. There is consumer resistance to the consumption of genetically modified crops.

Mr. KUCINICH. Why?

Mr. SMITH. I am not an expert to answer that.

Mr. KUCINICH. You don't have to answer.

Mr. Miller, your testimony explains that the dicamba/Roundup soybean is designed to "give growers more weed control options." It sounds somewhat artful. It sounds like an artful way of saying that farmers can't rely on Roundup to control weeds anymore, so they now need to use another pesticide.

Is it your belief, Mr. Miller, that the best solution to Roundup resistance in weeds is a farmer using another pesticide?

Mr. MILLER. I would say my belief, a broad array of university scientists, other industry scientists, the Weed Science Society of America, believes that adding multiple modes of action into an agricultural production system is good agricultural practice, Mr. Chairman.

Mr. KUCINICH. Thank you.

Mr. Freese, is the only or best way to control weeds after Roundup resistance has set in more and more chemicals and new chemical-tolerant crops?

Mr. FREESE. I think that is actually a very dangerous path to take.

Mr. KUCINICH. Why?

Mr. FREESE. We are learning lots of new things about weed resistance, and new mechanisms are being discovered all of the time.

Mr. KUCINICH. Why is it dangerous? You used the word "dangerous." What do you mean?

Mr. FREESE. I think it is dangerous because it is going to lead to greater resistance down the line.

Mr. KUCINICH. How do you know that?

Mr. FREESE. Because what we have seen is an increase in multiple herbicide-resistant weeds already.

Mr. KUCINICH. So you use more chemicals. And we had testimony earlier from Ann Wright about the evolution of crops that contain herbicide resistance generally, right?

Mr. FREESE. Yes. So, for instance, in the eighties and nineties, a popular class of herbicides was called the ALS inhibitor.

Mr. KUCINICH. And ALS stands for?

Mr. FREESE. Acetolactate synthase. And they generated a huge expanse of herbicide-resistant weeds, and those resistant weeds were one reason farmers adopted Roundup Ready crops. Now we are getting weed populations that are resistant to both herbicides.

In Missouri and Illinois, we have weed populations resistant to three and four different herbicides.

Mr. KUCINICH. For those who are not initiated, what are the implications of that? Draw out for us the practical implications that this scenario that you envision happening as a result of your scientific background—tell us where we are going.

Mr. FREESE. Well, we are headed toward more pesticide use, for one thing. That is pretty clear. At the last superweed hearing, one of the weed scientists spoke on the order of a 70 percent increase in 2,4-D and dicamba use soon after the introduction of the 2,4-D and dicamba-resistant soybeans.

Mr. KUCINICH. What happens then?

Mr. FREESE. One thing is you have greater levels of these residues of these herbicides on the crop. A little-known fact about herbicide-resistant crops is the companies seek increases in what are called tolerances, the maximum allowable residue of the pesticide on the crop. We have seen that repeatedly with Roundup Ready, greatly increased glyphosate tolerances each time a new Roundup Ready crop is approved.

Now, it is very troublesome when we think about that with more toxic herbicides like 2,4-D and dicamba, both of which have been linked to cancer in pesticide applicators and farmers. 2,4-D is a likely endocrine disrupter; that is, a disrupter of our hormone systems which are so important in controlling our development, our reproductive system, and our metabolism.

EPA was supposed to start looking at endocrine effects on all of our pesticides in 1998, but hasn't been funded to do that, and so it is only just now getting started.

Mr. KUCINICH. Are there any weed scientists to recommend an approach other than Monsanto's preference for dealing with weed resistance to their product Roundup.

Mr. FREESE. Can you restate that?

Mr. KUCINICH. Is there another approach that weed scientists would recommend in dealing with this problem of resistance?

Mr. FREESE. Yeah, and as a matter of fact, it's quite interesting because there is a technique that's long been used by organic growers, but also conventional growers. It involves planting winter cover crops. And basically it just—it means after harvest of the main crop, you can plant a cereal like rye, or a legume like hairy

vetch or clover. And this cover crop grows in the fall, and then more in the spring, and it holds the soil, and it also absorbs excess nitrogen and phosphorous fertilizer. And then in the spring, it's killed off and forms a thick mat into which you can plant your main crop, that mat suppresses weeds physically. Sometimes the cover crop also releases chemicals that inhibit the growth of weeds. It's a very, very beneficial practice, because again, it's effective—it effectively suppresses weeds and provides multiple other benefits as well.

Mr. KUCINICH. All right. I want to thank you for answering that. Did you want to add something, Mr. Vroom?

Mr. VROOM. Yes, Mr. Chairman. So we've delved into a lot of detail, but one important broad category of differentiation among weed control with regard to crop protection products is whether the chemistry is used after the weeds emerge, are sprayed on to the weeds, or it's applied to the soil as a pre-emergent control product.

The ALS herbicide Mr. Freese is talking about are pre-emergent products, they are applied to the soil before the crop is planted. And so the—while the registrants for those chemicals that are pre-emergent products oftentimes do have protective tolerance levels, should some tiny amount be left in the soil and then get into the crop plant, there's virtually no evidence of residual in the actual crop from those kinds of products that are applied by the farmers.

So big difference there between the technologies that all herbicides aren't applied the same way. And again, I think we come back to the industry, farmers, the USDA and the extension are all looking at redeploying a lot of old technologies—I'm certain that Monsanto and others have already reinvented some of the formulation technologies so that it can be better managed than it was when that particular product was more prominently used.

And so it's all part of the solution, and I think what you're drawing out here is that we all have to work together, reinvent old products, because we also have evidence, and I've got a study here that I would also like to ask you to consider submitting into the record by——

Mr. KUCINICH. You can submit it.

[The information referred to follows:]

AgriFAX Futura
McDougall AgriService

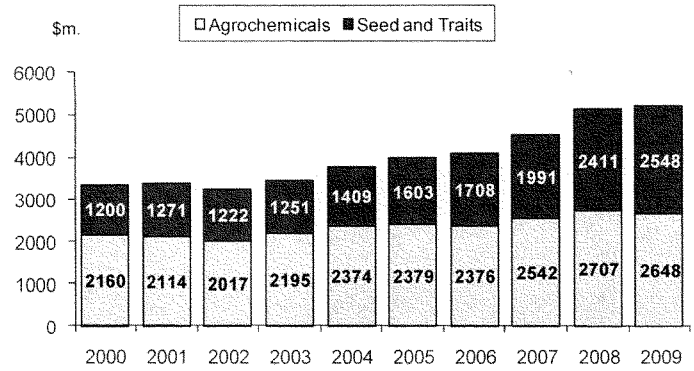
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Agrochemical Industry R&D

In 2009, the level of research and development expenditure for the fifteen leading companies within the agrochemical industry is estimated to have increased by almost 1.5% in nominal US dollar value to reach a total of $5196 m. Because of the relative change in the value of the US dollar versus the Euro during the year, in Euro terms the increase is closer to 7.0%.

Since 2000, the overall level of R&D expenditure incurred by the 15 leading companies in the agrochemical sector has grown at a compound annual growth rate (CAGR) of 5.0%, raising the level of R&D expenditure from $3360 million to a total of $5196 million in 2009.

Total R&D Expenditure by the Leading Agrochemical Companies



Although the overall level of R&D expenditure by these 15 leading companies increased in 2009, the value of expenditure devoted to conventional agrochemical R&D actually fell back by 2.2% in nominal terms in 2009 to reach $2648m. In contrast to this the level of R&D expenditure devoted by these fifteen leading companies in the seed and trait sector, in the same time period, increased by 5.7% in 2009 over 2008 to reach $2548 m.

As outlined above, one of the key factors driving industry R&D expenditure has been the increasing focus by several of the leading companies on the seed and trait sector. As a result of the higher rate of growth, the overall proportion of the R&D budget of the fifteen leading companies devoted to the seed and trait sector has increased from 35.7% in 2000 to reach 49.0% last year. This result reflect a compound growth rate (CAGR) of 8.7% per annum in seed and trait R&D since 2000, compared to the equivalent value of 2.3% per annum for conventional agrochemical R&D expenditure.

It is evident that the environment for chemical crop protection R&D is becoming exceedingly more competitive, the cost of developing a new active ingredient is increasing (see AgriFutura 125, March 2010), whilst the regulatory environment is also becoming stricter, particularly in the EU with the updating of the requirements for re-registration. This coupled with the shift in R&D focus by the major companies to seeds and traits and the consolidation of the industry has not only reduced the number of companies involved in basic agrochemical R&D, but also resulted in these companies becoming more selective regarding which product candidates are selected to advance from research into development. These combined factors have resulted in fewer new active ingredients being introduced.

It is also evident that the growth in the uptake of GM crops has resulted in a reduction of R&D activity in sectors affected by GM technology, notably soybean herbicides and cotton insecticides. Whilst a number of new insecticides for Lepidoptera control have been introduced recently, it is notable that the key crop focus for these products is fruit & vegetables, rather than the traditional market for Lepidoptera control products, cotton, a sector which is now dominated by B.t. technology.

Product Introductions and R&D by Crop

Number of new Active Ingredients		Time period			
		1980/1989	1990/1999	2000/2009	In R&D
Herbicides	Cereals	15	12	12	3
	Soybean	11	10	1	0
	Maize	2	10	9	1
	Rice	11	19	14	4
	F&V	2	1	0	1
	Other	10	5	2	1
	Total	51	57	38	10
Insecticides	F&V	11	16	15	6
	Rice	5	2	3	3
	Cotton	9	12	3	1
	Others	4	7	5	3
	Total	29	37	26	13
Fungicides	F&V	13	9	17	6
	Cereals	14	16	8	8
	Rice	9	5	7	5
	Others	0	0	0	1
	Total	36	30	32	20
Others		7	3	5	1
Total		123	127	101	44
Average annual rate of introduction		12.3	12.7	10.1	8.8

The final line of the table shows the average rate of new active ingredient introduction by decade, and indicates a slowdown in the rate of new products coming to the market. At present there are 44 product candidates in the development stage, which are anticipated will enter the market within the next five years. If this is realized then the average rate of new introduction will fall to 8.8 products per annum, in comparison with 10 per annum in the 2000s and 12.7 per annum in the 1990s.

Despite the attractions of the seed sector, significant opportunities in the agrochemical market are still evident, notably as a result of re-registration issues in the EU and especially following the adoption of revised regulations at the end of 2009. As endocrine disruption is becoming an issue, the registrational position of a number of products has been brought in to question, some of which hold important positions in resistance avoidance strategies. Removal of these products from the market would clearly create an opportunity for new active ingredients.

The table below compares R&D expenditure with market performance since 2000.

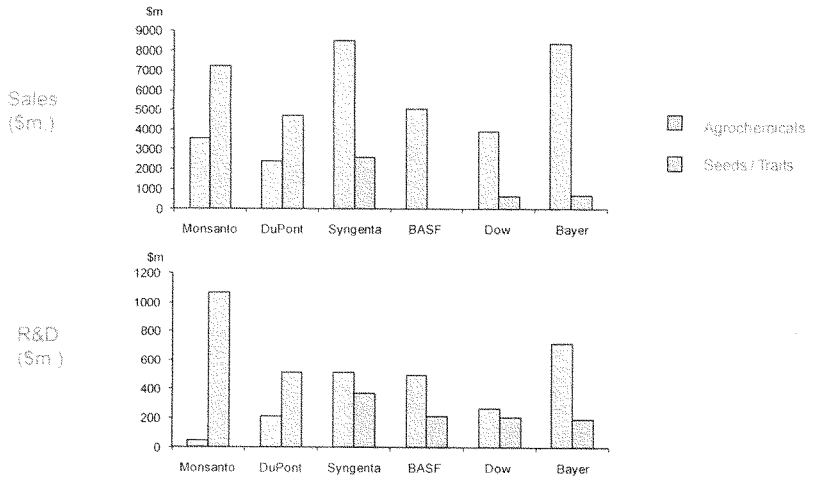
R&D Expenditure Compared to Market Performance

Market $m	2000	2008	2009	2009/08 %	2009/00% p.a.
GM Seed	2194	9150	10570	15.5	19.1
Conventional Seed	14269	16870	16160	-4.2	1.4
Total Seed	**16463**	**26020**	**26730**	**2.7**	**5.5**
Agrochemical	31977	46130	43720	-5.2	3.5
Overall Total	**48440**	**72150**	**70450**	**-2.4**	**4.2**

R&D $m	2000	2008	2009	2009/08 %	2009/00% p.a.
Seed and Traits	1200	2411	2548	5.7	8.7
Agrochemicals	2160	2707	2648	-2.2	2.3
Overall Total	**3360**	**5118**	**5196**	**1.5**	**5.0**

Since 2000, the total seed market (GM and Conventional) has grown at an average annualised rate of 5.5% p.a., whilst Seed and Trait R&D expenditure for the leading 15 agrochemical companies has increased on average by 8.7% p.a. Over the same period the agrochemical market (crop protection and non-crop) has grown by 3.5% p.a., whilst R&D expenditure of the top 15 companies has grown by only 2.3% p.a. indicating the continuing shift in R&D expenditure towards the seeds and traits area.

Company Sales and R&D Expenditure 2009



In 2009, Monsanto was the leading company in terms of R&D expenditure on agrochemicals and seeds & traits. It is clear that almost all R&D expenditure by Monsanto is devoted to the seeds and traits area, with a modest level of agrochemical R&D limited to product defense, formulation development and seed treatments; the company is no longer involved in the research of new chemical active ingredients. The second leading company, again both in terms of sales and R&D expenditure, is Bayer. Over the last few years, Bayer has been increasing the proportion of its R&D budget to seeds and traits however currently the majority of the R&D budget is targeted at conventional agrochemical R&D.

Analysis of the active ingredients that have left the EU market due to either not being supported through re-registration, or not achieving acceptance, indicates that the market sector most affected has been fruit & vegetables. An increasing focus of R&D on fruit & vegetable insecticides and fungicides is now evident, not only with chemical crop protection products, but also with biologicals.

In addition to the R&D products listed in the table above, there are also believed to be around 50 active ingredients in development in China, the majority are understood to be analogues of chemistry already introduced outside China. These products are not included in this analysis as the majority do not have GLP registration packages; hence the potential for their introduction in markets outside China is limited.

If the rate of active ingredient introduction of the major companies also involved in R&D in the seed sector is compared with time, then a slowdown in new product introduction can be seen. Over the same time period the rate of introduction from companies not involved in seed R&D has increased.

Rates of New Active Ingredient Introduction

	A.I. introductions since 1980	Rate p.a.	A.I. introductions since 1994	Rate p.a.
Companies with Seed R&D	213	7.1	99	6.6
Others	138	4.6	79	5.3
Total	**351**	**11.7**	**178**	**11.9**

It can be seen that the rate of new active ingredient introduction by the companies involved in seed R&D has declined from 7.1 products per annum on average over the last thirty years to 6.6 p.a. over the last fifteen years. Conversely, the rate of introduction from other companies has increased from 4.6 p.a. to 5.3 p.a. over the same periods.

Active Ingredient Introduction and in R&D by Company

	Introduced 1994-2009	Currently in R&D
Bayer	35	6
Syngenta	17	5*
BASF	19	5*
Dow	19	2
Sumitomo	15	2*
DuPont	7	3*
Monsanto	1	0
Other Japanese	44	18
Rest	21	5
Total	178	46**

* Some in co-development with other companies
** some licensed products counted twice

For the future it seems likely that investment in seed and trait R&D will continue to outpace that of agrochemicals. In 2009 the overall spend on R&D for agrochemicals, by the leading fifteen companies was $2648 m., down 2.2%, whilst expenditure by these companies on seed and trait R&D increased by 5.7% to $2548 m. With the crop protection market forecast to grow at 1.8% p.a. through to 2014 in 2009 dollar terms, and the GM sector anticipated to expand by 4.0% p.a. over the same period, it is likely that this shift in R&D emphasis is likely to continue.

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Mr. VROOM. McDougal organization that shows that in the decade of the 1980's and 1990's, our crop protection companies were able to discover and bring to market more than 50 new herbicide products. In the decade of the 2000's, that number has dropped to 38. And so it's just a reminder that while our research goes on, we found the ease to discover and most broad spectrum efficacious herbicides, and now we're needing—now we're looking for things that are much more targeted and the need to reinvent the older products that are proven safe that can be reformulated and applied by farmers in different ways. Thank you.

Mr. KUCINICH. Thank you very much. I would just like to say in response to the point that you raise something that's obvious, that we're really probing here into cause and effect. Some causal chains begin in nature. With biotechnology and genetic engineering, some causal chains begin in the laboratory. So we just are trying to find out which way things are going here, and doing the best we can.

Mr. VROOM. Thank you.

Mr. KUCINICH. Thank you for being here. I want to thank each of the witnesses. You've given this subcommittee additional information; we'll continue to seek more. We're going to do it in a dispassionate way. Just try to gather information so that we can recommend policies that would be in the best interest of all parties concerned.

I do take note of Mr. Miller's testimony that government does have a role to play, it's not only the industry that's the question here, and I appreciate that you raise that.

So without any further testimony, this is the Domestic Policy Subcommittee of Oversight and Government Reform. The subject of today's hearing "Are 'Superweeds' an Outgrowth of USDA Biotech Policy?" This is the second part of this hearing.

The subcommittee will continue to retain jurisdiction over this matter. I want to thank the staff for its presence here today and its participation in helping to structure this hearing. There being no—and thank the witnesses certainly. There being no further businesses before this subcommittee, this subcommittee stands adjourned. Thank you.

[Whereupon, at 4:08 p.m., the subcommittee was adjourned.]

[Additional information submitted for the hearing record follows:]

Response to Questions From the Domestic Policy Subcommittee of the House Oversight and Government Reform Committee

With Regard to Herbicide-Resistant Weeds Following Testimony Delivered Before the Subcommittee on September 30, 2010

by William Freese
Science Policy Analyst
Center for Food Safety

What does your research reveal about when Monsanto should have known and reacted to development of Roundup-resistant weeds?

Prior to the confirmation of the first glyphosate-resistant weed population in 1996, weed scientists had collected abundant evidence showing that resistant weeds were likely to evolve with frequent use of glyphosate. For instance, Duncan & Weller (1987) conducted experiments on five biotypes of field bindweed that had been shown by DeGennaro & Duncan (1984) to have substantial variability in their tolerance to glyphosate. They concluded from their experiments that: "These results further suggest that glyphosate tolerance in a field bindweed population could be enhanced by selection pressure in the form of ***repeated glyphosate applications***."[1] Boerboom et al (1990) similarly found a three-fold range of glyphosate tolerance in specimens of the weed birdsfoot trefoil.[2] As with field bindweed, repeated glyphosate applications would kill off the more susceptible types, leaving the more tolerant to propagate, potentially leading to a resistant population quite rapidly.[3]

In 1996, the eminent weed scientist Dr. Jonathan Gressel reviewed some of the evidence pointing to the likelihood that glyphosate-resistant weeds would emerge, and rebuked Monsanto scientists for giving the false impression that glyphosate was "invincible" to

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[1] DeGennaro, F.P. & S.C. Weller (1984). "Differential susceptibility of field bindweed (*Convolvulus arvensis*) biotypes to glyphosate," Weed Science 32: 472-476; Duncan, C.N. & S.C. Weller (1987). "Heritability of glyphosate susceptibility among biotypes of field bindweed," The Journal of Heredity 78: 257-60.

[2] Boerboom, C.M. et al (1990). "Mechanism of glyphosate tolerance in birdsfoot trefoil," Weed Science 38: 463-467.

[3] Although "tolerance" and "resistance" to herbicides are formally distinct, in practice the terms are often used interchangeably by weed scientists. In common usage, tolerance denotes a weed that withstands lower doses of an herbicide, while resistant weeds survive higher doses.

resistance.[4] Dr. Gressel first presented the following excerpt of a paper written by Monsanto scientists Steven Padgette and colleagues for a symposium in Spain.[5]

> "Evolution 'of weed resistance to glyphosate appears to be an unlikely event, based on the ***lack of weeds or crops that are inherently tolerant to glyphosate*** and the long history of extensive use of the herbicide resulting in no resistant weeds. ***Unique properties*** of glyphosate such as its mode of action, chemical structure, limited metabolism in plants, and lack of residual activity in soil indicates that ***the herbicide exerts low selection pressure*** on weed populations' (Padgette et al 1995)." (emphasis added)

As noted above, at least two weeds had been shown in peer-reviewed studies in the 1980s and 1990 to have precisely the "inherent tolerance to glyphosate" of which Monsanto's Padgette and colleagues profess ignorance in 1995. Many other weeds, such as morninglories, yellow nutsedge, field horsetail, prairie cupgrass, wild buckwheat, and dayflower species have long been recognized as glyphosate-tolerant.[6] The statement that glyphosate "exerts low selection pressure on weed populations" is grossly misleading, in that it considers only certain chemical properties of glyphosate, and ignores the much more important factor of how glyphosate is used. The frequency, intensity and timing of glyphosate use with Roundup Ready crops generate tremendous selection pressure for evolution of resistant weeds, whatever "unique properties" the glyphosate molecule may or may not possess.

Dr. Gressel's commentary on the quote presented above makes it clear that Monsanto scientists were not innocently wrong, but rather guilty of intentional misrepresentation. Speaking directly to Padgette and colleagues' 1995 paper that contains the statement quoted above, Gressel said:

> "The impression of invincibility from resistance was enhanced by ***not citing*** the growing literature on the known inter-, and especially intra-specific, genetic variability in quantitative levels of glyphosate resistance. ***This literature was known to the various authors,*** yet must have been considered irrelevant. ***In turn, this led to dismissing the need to set resistance management strategies in motion, and the ensuing appearance of a glyphosate-resistant population*** in the management system and the weed where it was most likely to occur." (emphasis added).

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[4] Gressel, J. (1996). "Fewer constraints than proclaimed to the evolution of glyphosate-resistant weeds," Resistant Pest Management Newsletter, Vol. 8, No. 2 (Winter 1996), pp. 20-23. http://whalonlab.msu.edu/Newsletter/pdf/8_2.pdf.

[5] Padgette, S.R., X. Delannay, L. Bradshaw, B. Wells & G. Kishore (1995). "Development of glyphosate-tolerant crops and perspectives on the potential for weed resistance to glyphosate," in: International Symposium on Weed and Crop Resistance to Herbicides, Cordoba, Spain. Abstract 92.

[6] Boerboom, C. & M.D. Owen (2006). "Facts about Glyphosate-Resistant Weeds," The Glyphosate, Weeds and Crop Series, Purdue University Extension, Dec. 2006. http://www.extension.purdue.edu/extmedia/GWC/GWC-1.pdf.

Dr. Gressel goes on to discuss the ample evidence for likely resistance that Monsanto scientists had conveniently ignored. For instance, he cites and discusses eight published scientific articles that present ***eight different mechanisms*** by which weeds might evolve resistance to glyphosate. The lead author of one of these papers was Monsanto scientist Stephen Padgette. We discuss Dr. Gressel's reference to a glyphosate-resistant weed population below.

Why would Monsanto scientists misrepresent this important issue of glyphosate's potential to foster glyphosate-resistant weeds? (And they did this not only in Padgette et al (1995), but in a flurry of papers presenting essentially the same distorted view, for instance: Bradshaw et al (1995), Padgette et al (1996) and Bradshaw et al (1997)[7]). The answer is clear. In the mid 1990s when these papers appeared, Monsanto was in the midst of launching the company's first Roundup Ready (RR) crop, RR soybeans, which were first planted commercially in 1996. While Monsanto's microscopic focus on the supposedly "unique properties" of the glyphosate molecule had some success in quelling resistance concerns (e.g. see Jasienuik 1996),[8] most weed scientists were not fooled. Dr. Gressel and many others were convinced that Roundup Ready crop systems would likely do what two decades of glyphosate use had thus largely far failed to do: foster rapid evolution of GR weeds.

As early as 1990, public interest scientists published a strong critique of the herbicide-resistant (HR) crop paradigm entitled *Biotechnology's Bitter Harvest*, which highlighted the high potential for HR weed evolution presented by HR crop systems, among other risks, such as increased use of toxic herbicides.[9] In 1992, Dr. Rebecca Goldburg (co-author of *Biotechnology's Bitter Harvest*) published a peer-reviewed paper in the journal *Weed Technology*, which made similar points. Interestingly, Dr. Goldburg conceded that HR crops resistant to newer and safer herbicides (e.g. glyphosate vs. older, more toxic herbicides like 2,4-D) might offer some short-term benefits in terms of displacing more toxic herbicides, but cautioned that: "resistant weeds already limit use of some of the newer chemicals, and the availability of crops that tolerate the newer herbicides could further encourage the evolution of resistant weeds..."[10]

Weed scientist Dr. Brian Sindel (1996) made the same point in an article discussing the first glyphosate-resistant weed population (discussed further below), quoting his colleague Dr. Roger Cousens of Latrobe University to the effect that herbicide-resistant crops that rely entirely on herbicides for weed control are "in danger of crashing down around our

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[7] See Gressel (1996), op. cit., for references.

8 Jasieniuk, M. (1996). "Constraints on the evolution of glyphosate resistance in weeds," Resistant Pest Management Newsletter, Vol. 7, No. 2 (Winter 1995), pp. 25-26. http://whalonlab.msu.edu/Newsletter/pdf/7_2.pdf.

[9] Goldburg, R., J. Rissler, H. Shand, C. Hassebrook (1990). *Biotechnology's Bitter Harvest: Herbicide-Tolerant Crops and the Threat to Sustainable Agriculture,* Biotechnology Working Group, March 1990.

[10] Goldburg, R. (1992). "Environmental concerns with the development of herbicide-tolerant plants," Weed Technology 6: 647-652.

ears" due to weeds developing resistance to herbicides.[11] Dr. Sindel also explained why glyphosate had thus far fostered so little weed resistance. Used as a "pre-sowing, knockdown herbicide" (Australian terminology for pre-emergence burndown use) with conventional crops, any resistant weeds would likely be killed off by tillage or subsequent use of other herbicides. Such would not be the case with Roundup Ready crops, where glyphosate would likely be the only weed control tool applied. Dr. Sindel concluded by stating that "glyphosate must be retained as an effective herbicide. Integrated weed management, a combination of weed control techniques, is promoted to avoid the further emergence of herbicide resistance."[12]

In 1997, Dr. Ian Heap, who has long managed an online database that registers the occurrence of herbicide-resistant weed populations worldwide, also warned of the need for resistance management with Roundup Ready crops:

> "The recently developed glyphosate-resistant crops ***will need to be used in rotation with conventional cultivars, and in conjunction with non-chemical weed control*** and other herbicides if the selection of glyphosate-resistant weeds is to be avoided." (emphasis added).[13]

Finally, we cite a prescient 1992 article by EPA scientist Dr. Diana Horne in the journal *Weed Technology* entitled "EPA's response to resistance management and herbicide-tolerant crop issues."[14] In 1992, U.S. regulation of genetically engineered (GE) crops was still in the planning stages, and EPA's role had not yet been fixed. While it was clear that EPA would regulate insecticide-producing insect-resistant GE crops by virtue of its traditional role as pesticide regulator, "EPA's role in the regulation of herbicide-tolerant (HTC) varieties is more oblique. EPA has no direct authority over the plant, as herbicide tolerance does not include production of pesticidal compounds. But, EPA will regulate new herbicide uses."

Dr. Horne went on to discuss the widespread occurrence of weeds resistant to other herbicides, and EPA's "strong interest in promoting the development and broader use of integrated pest management (IPM) technologies" to forestall evolution of resistant insects and weeds and reduce use of herbicides overall and their adverse environmental impacts. In a passage that could not have escaped Monsanto, she posed the following question:

> "Would it be appropriate, for example, for the Agency to require that transgenic plants (both of the pesticidal, as well as the herbicide-tolerant varieties), be used ***only within the context of a resistance management program***?" (emphasis added)

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[11] Sindel, B. (1996). "Glyphosate resistance discovered in annual ryegrass," Resistant Pest Management Newsletter, Vol. 8, No. 2 (Winter 1996), pp. 23-24.
[12] Ibid.
[13] Heap, I. (1997). "Occurrence of herbicide-resistant weeds worldwide," Pesticide Science 51: 235-243.
[14] Horne, D. (1992). "EPA's response to resistance management and herbicide-tolerant crop issues," Weed Technology 6: 657-661.

Unfortunately, Dr. Horne's paper was prescient only in its discernment of the weed resistance threat posed by HR crop systems. While EPA went on to institute mandatory resistance management for insect-resistant GE crops, its halting efforts to establish even weak voluntary weed resistance management plans for glyphosate-resistant and other HR crops foundered on opposition from HR crop developers and growers.[15]

Why were Monsanto scientists virtually alone in denying the threat of glyphosate-resistant weeds? The answer seems clear. Any resistance management plan with a chance to be effective would have to limit selection pressure by imposing restrictions on the use of glyphosate and/or Roundup Ready crops. This is consistent with Dr. Heap's statement above that RR crops would need to be rotated to conventional cultivars to avert further weed resistance. We note that EPA's successful insect resistance management (IRM) plans for insect-resistant crops involves the requirement that growers plant substantial refugia of non-Bt corn and cotton alongside their Bt crop plantings.[16] In short, resistance management would have meant a perhaps substantial crimp in Monsanto's profits via reduced sales of glyphosate and RR crop seed. Another important factor is that farmers often respond to lower-level glyphosate-resistance in weeds by "increasing the magnitude and frequency of glyphosate applications"[17] – a counterproductive, but for Monsanto profitable, response. This helps explain why Monsanto has always recommended using the "full rate" of glyphosate as its keystone "weed resistance prevention" strategy, despite rebukes from weed scientists that use of alternatives to glyphosate is the proper response.[18]

Still, didn't Monsanto understand that it had a longer-term financial interest in preventing the evolution of glyphosate-resistant weeds so as to prolong the useful life of its Roundup Ready technology? Dr. Gressel in fact appeals to Monsanto with this "enlightened self-interest" argument in the conclusion of his piece, cited above. CFS believes that such appeals are based on a misunderstanding of the market forces guiding biotechnology-pesticide firms such as Monsanto.

First, consider that pesticide industry has long familiarity with weed resistance, which has been evolving since the 1970s. Second, that the pesticide treadmill phenomenon whereby a frequently used herbicide fosters resistance, leading to supplementation or replacement with a new "mode of action" (different type of herbicide), has been a major driver in the pesticide industry's development and sale of new herbicides. Finally, consider that the

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[15] Jones, Jim (2010). Testimony before the Domestic Policy Subcommittee, House Oversight and Government Reform Committee, Sept. 30, 2010. Mr. Jones is the EPA's Deputy Assistant Administrator for Chemical Safety and Pollution Prevention.
http://oversight.house.gov/index.php?option=com_content&view=article&id=5121:webcast-and-testimony-for-hearing-are-superweeds-an-outgrowth-of-usda-biotech-policy-part-ii&catid=66:hearings&Itemid=31.

[16] Jones (2010), op. cit.

[17] NRC (2010). *The Impact of Genetically Engineered Crops on Farm Sustainability in the United States,* National Research Council, National Academy of Sciences, 2010 (pr-publication copy), p. 2-15.

[18] Hartzler, B. (2004). Weed Science, Iowa State University, December 17, 2004. http://www.weeds.iastate.edu/mgmt/2004/twoforone.shtml; Hartzler, B. et al (2004). "Preserving the value of glyphosate," Iowa State University, Feb. 20, 2004, a joint statement by 12 leading Midwestern weed scientists. http://www.weeds.iastate.edu/mgmt/2004/preserving.shtml.

most profitable period for sale of patented HR seeds and their associated herbicides is limited to the 20-year terms of the associated patents.

Glyphosate went "off-patent" in the year 2000. Despite competition from cheaper generic versions of glyphosate, Monsanto continued to sell large quantities of its Roundup formulations of glyphosate after the year 2000 by tying the use of Roundup to its patented Roundup Ready seeds.[19] The major patent on Roundup Ready soybeans (the largest acreage RR crop) expires in 2014.[20] For a variety of reasons, Monsanto has been relatively unsuccessful in selling farmers on its second generation RR2 soybeans: some object to their high price; others that they do not provide the promised yield boost; and still others find the value of the technology eroded by glyphosate-resistant weeds, which require use of expensive, supplemental herbicides anyway.[21] For many, it is a combination of these factors – more expensive seed plus the expense of additional herbicides to combat GR weeds. When Roundup Ready 1 soybeans go off-patent in 2014, cheap generic versions will presumably become available; and farmers will likely have the legal right to save and replant them, offering further potential savings. Finally, other firms are poised to introduce their own glyphosate-resistant crops, posing a competitive challenge to the company.[22] In short, Monsanto could be facing the imminent loss of its lucrative Roundup Ready soybean franchise, followed by loss of market share in Roundup Ready corn and cotton when their associated patents expire.

What would persuade farmers to continue buying Monsanto soybeans, corn and cotton? One strong enticement would be the ability to control glyphosate-resistant weeds. Indeed, Monsanto has developed and is awaiting USDA approval of soybean varieties resistant to the broad-spectrum herbicide dicamba, which will be "stacked" with resistance to glyphosate as well.[23] These dual HR soybeans are being offered as a tool to help manage glyphosate-resistant weeds. Triple-stack versions of corn and cotton – which combine resistance to dicamba, glyphosate and a third herbicide, glufosinate – are not far behind.[24]

Finally, consider the market potential for these dual and triple-stack HR crops, which will certainly be more expensive than their Roundup Ready-only predecessors. Clearly, those farmers with GR and other HR weed-infested fields would be the most likely market, since

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[19] Barboza, D. (2001). "The Power of Roundup; A Weed Killer Is a Block For Monsanto To Build On," New York Times, August 2, 2001. http://www.nytimes.com/2001/08/02/business/the-power-of-roundup-a-weed-killer-is-a-block-for-monsanto-to-build-on.html.

[20] Pollack, A. (2009). "As patent ends, a seed's use will survive," New York Times, December 18, 2009. http://www.nytimes.com/2009/12/18/business/18seed.html.

[21] Agrimoney (2010). "Monsanto faces revenue risk if seed drive misfires," Agrimoney, August 16,2010. http://www.agrimoney.com/news/monsanto-faces-revenue-risk-if-seed-drive-misfires--2111.html; Bennett, D. (2009). "Conventional soybeans draw interest," Delta Farm Press, April 3, 2009, http://deltafarmpress.com/soybeans/conventional-soybeans-0403/.

[22] See recent entries for glyphosate-tolerant crops – Stine Seed, Bayer CropScience and Pioneer – at http://www.aphis.usda.gov/biotechnology/not_reg.html.

[23] Monsanto (2010a). "Monsanto completes key regulatory submission for soybeans withy dicamba herbicide tolerance trait," News Release, July 13, 2010. http://monsanto.mediaroom.com/index.php?s=43&item=863

[24] Monsanto (2010b). "Monsanto Announces Record 11 Project Advancements in Annual Research and Development Pipeline Update," News Release, Jan 6, 2010.

those without resistant weeds would have little incentive to purchase pricier multiple HR crops if cheaper Roundup Ready-only varieties do the job. Glyphosate-resistant weeds are currently estimated to infest 6% of the 173 million acres planted to soybeans, corn and cotton in the U.S., or 10.4 million acres.[25] This represents roughly four-fold greater acreage than in late 2007, when CFS collated figures from the same definitive data source on resistant weeds and found the GR weed-infested acreage totalled just 2.4 million acres. Though no one can say with certainty how rapidly GR weeds will emerge in the future, Syngenta's weed resistance manager, Chuck Foresman, estimates that 38 million acres – or one of every four row crop acres – will be infested with GR weeds in the U.S. by the year 2013.[26] This 38 million acres of GR weed-infested fields would represent a substantially greater market opportunity for the sale of Monsanto's dual and triple-resistant HR crops than the current 10 million acres. Clearly, glyphosate-weed evolution opens up substantial new marketing opportunities for Monsanto. In contrast, serious stewardship measures to slow or stop GR weed evolution works against the company's financial interest.

It will perhaps be objected that this is a cynical interpretation of Monsanto's motives. Not at all. CFS is intimately familiar with Monsanto's long-standing voluntary stewardship efforts with Roundup Ready crops, whose ostensible purpose is indeed to slow the emergence of GR weeds. While it is beyond the scope of these comments to elaborate, we have done so elsewhere, demonstrating that some of Monsanto's supposed resistance management recommendations are not only ineffectual, but exacerbate the problem by supporting continual planting of Roundup Ready crops every year.[27] However, the bottom line of rapidly expanding GR weed populations speaks more than any analysis to the inefficacy of Monsanto's recommendations. Of course, having such programs in place is good public relations. And it must be said that biotech-friendly USDA regularly touts such voluntary, Monsanto-sponsored measures as an excuse not to take regulatory action, ignoring their failure.[28] Recall, however, that the EPA's Jim Jones has testified that biotech companies successfully foiled weak attempts by EPA and USDA to introduce voluntary weed resistance management programs under their auspices in 2001. As virtually the sole provider of genetically engineered HR crops at that time, the objectors must have included Monsanto.

Yet in fairness, it should be stated that Monsanto is not alone in anticipating considerable profits from the GR weed epidemic. As recently reported in the Wall Street Journal, pesticide-biotechnology companies are investing hundreds of millions of dollars in new HR crops as a temporary hi-tech "fix" to glyphosate-resistant weeds. Dow Agrosciences scientist Jim Jachetta stated that these new HR crops represent "a very significant

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[25] USDA APHIS (2010). "Draft environmental assessment of supplemental request for partial deregulation of sugar beet genetically engineered to be tolerant to the herbicide glyphosate," USDA Animal and Plant Health Inspection Service, October 2010, p. 93.
[26] Syngenta (2009). "Leading the fight against glyphosate resistance," http://www.syngentaebiz.com/DotNetEBiz/ImageLIbrary/WR%203%20Leading%20the%20Fight.pdf.
[27] CFS (2010). CFS Science Comments on USDA APHIS's draft environmental assessment for partial deregulation of Roundup Ready sugar beets," Dec. 6, 2010. http://www.centerforfoodsafety.org/wp-content/uploads/2010/12/RRSB-Partial-Dereg-EA-Science-Comments-BF.pdf.
[28] USDA APHIS (2010), op. cit.

opportunity" and "a new era" for chemical companies.[29] Mr. Jachetta was probably thinking in particular of Dow's new corn and soybeans varieties that resist high doses of 2,4-D, a close chemical cousin of dicamba that formed part of the Vietnam War defoliant Agent Orange. Dow took the opportunity of press attention to the GR weed epidemic to issue a press release touting its 2,4-D tolerant crops as a fix to GR weeds.[30]

When should Monsanto have known and reacted to the development of Roundup-resistant weeds? The short answer is, no later than the introduction of the first Roundup Ready crop in 1996. As documented above, there was widespread concern in the weed science community that Roundup Ready systems would foster GR weeds, and Monsanto scientists not only ignored the evidence, but in several publications intentionally gave the false impression that resistant weeds would not emerge, so as to avoid resistance management regulations that the EPA was seriously considering, and that would have limited the company's profits.

However, there is also solid evidence that Monsanto scientists denied the existence of the first confirmed GR weed population, rigid ryegrass in Australia, in a peer-reviewed scientific publication. This is the GR weed population referred to by Dr. Gressel (in the above-cited article), who stated that Australian researchers had confirmed to him its existence in discussions at a weed science conference in June of 1996. The Australian press had reported the resistant ryegrass even before that. In another paper (also cited above) appearing in the same issue of the same journal as Dr. Gressel's, Dr. Brian Sindel stated that: "Researchers at the Centre for Conservation Farming at Charles Stuart University at Wagga Wagga ***confirmed*** that the ryegrass was resistant to glyphosate," and that Monsanto Australia's Bill Blowes was working with the University to determine the cause of the resistance. Nevertheless, Monsanto scientists said not a word about this GR weed in a 1997 paper that appeared in the journal *Weed Technology*,[31] and in fact repeatedly denied the existence of any "verified" GR weed population in world, despite the confirmation cited above.[32] Though the editors received the original paper in April of 1995, they note that a revised version was received on July 17, 1996 – at least weeks and probably months after University researchers had confirmed the resistance.

This historical footnote, however revealing it may be as to Monsanto's (lack of) corporate character, is of minor importance now. Much more significant is the company's ***continuing*** obfuscation of the glyphosate-resistant weed issue, even today, as it strives to introduce new Roundup Ready crops (such as alfalfa and sugar beets) free from the regulation that is urgently

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[29] As quoted in: Kilman, S. (2010). "Superweed outbreak triggers arms race," Wall Street Journal, June 4, 2010.

[30] Kaskey, J (2010). "Dow plans new trait to combat Roundup-resistant weeds," Bloomberg, May 05, 2010, http://www.businessweek.com/news/2010-05-05/dow-plans-new-trait-to-combat-roundup-resistant-weeds-update2-.html.

[31] Bradshaw, L. et al (1997). "Perspectives on glyphosate resistance," Weed Technology 11: 189-198.

[32] In one passage that reveals they know of the resistant population, Bradshaw and colleagues tellingly state that "evidence of weeds evolving resistance to this herbicide [glyphosate] under field situations has not been verified," citing two papers from 1993 and 1994. Elsewhere in the paper, they state: "no verified reports of a glyphosate-resistant plants have arisen following an extensive history of broad-scale glyphosate applications in the field." Yet as noted by Dr. Gressel, the population had been confirmed as resistant by no later than June of 1996.

needed to prevent further epidemic spread of weed resistance. Monsanto's position today is that planting a GR crop every year in the same field is consistent with forestalling GR weed evolution, provided only that it is not the same GR crop every year. This position – uncritically adopted by USDA[33] – stands in direct contradiction to the concensus view of every legitimate member of the weed science community, as expressed in a recent National Research Council report, which stated explicitly that the value of crop rotation to forestall glyphosate-resistant weeds is undermined when the crops in the rotation are glyphosate-resistant.[34]

Thus, the question of when should Monsanto have known and reacted to the development of Roundup-resistant weeds is perhaps wrongly put, as it implies that the company has in fact reacted in an effective manner to glyphosate-resistant weeds. The truth, however, is that Monsanto continues to employ its considerable expertise not to forestall GR weeds, but rather to obfuscate the issue. This in turn serves to the interests of avoiding any serious resistance management, selling as many Roundup Ready seeds and as much Roundup as possible, and generating (via GR weeds) market demand for its successor herbicide-resistant crops.

Can you elaborate on why multiple-resistant crops are not, as some claim, a solution to the resistant weed epidemic?

Agrichemical-biotechnology companies have invested hundreds of millions of dollars in the development of crops resistant to high rates of older, more toxic herbicides as the supposed "solution" to glyphosate-resistant weeds.[35] In most cases, such crops are resistant to multiple herbicides, often including glyphosate.

Prominent examples include corn, soybeans and cotton resistant to 2,4-D, developed by Dow Agrosciences; and soybeans, corn and cotton resistant to dicamba, developed by Monsanto. Dow's 2,4-D resistant corn also resists the "fop" class of ACCase inhibiting herbicides,[36] and will be offered with resistance to glyphosate and/or glufosinate as well for triple or "quad-stack" resistance to three or four major classes of herbicide. Dow's soybeans will be resistant to glufosinate and glyphosate as well as 2,4-D, for "triple-stack" resistance to three herbicide families.[37] Monsanto's dicamba-resistant soybeans will also be resistant to glyphosate, while the company has triple-stack versions of corn and cotton in the works that resist dicamba, glufosinate and glyphosate.[38] There are many other

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[33] CFS (2010), op. cit.

[34] NRC (2010), op. cit., pp. 2-19, 2-20. See CFS (2010) for further support.

[1] Kilman, S. (2010). "Superweed outbreak triggers arms race," Wall Street Journal, June 4, 2010.

[36] Wright, T.R. et al (2010). "Robust crop resistance to broadleaf and grass herbicides provided by aryloxyalkanoate dioxygenase transgenes," PNAS 107: 20240-45.

[37] See corresponding entries at USDA's list of genetically engineered crops pending nonregulated status, at http://www.aphis.usda.gov/biotechnology/not_reg.html. For Dow's plans to "stack" their 2,4-D-resistant crops with glyphosate resistance, see: Kaskey, J (2010). "Dow plans new trait to combat Roundup-resistant weeds," Bloomberg, May 05, 2010, http://www.businessweek.com/news/2010-05-05/dow-plans-new-trait-to-combat-roundup-resistant-weeds-update2-.html.

[38] Monsanto (2010a). "Monsanto completes key regulatory submission for soybeans withy dicamba herbicide tolerance trait," News Release, July 13, 2010. http://monsanto.mediaroom.com/index.php?s=43&item=863.

examples from other companies. In fact, fully eleven HR crops are awaiting deregulation (approval for commercial cultivation) by USDA. These include 2,4-D resistant corn and soybeans and dicamba-resistant soybeans.[39]

The agrichemical-biotechnology industry intends for these crops to be sprayed with either premixed herbicide cocktails containing some or all the herbicides to which the crop is resistant, or with one or more of them sequentially, on an as-needed basis.[40]

The rationale behind these multiple HR crop systems is simple. Weeds resistant to one herbicide mode of action will be killed by the other(s). Unfortunately, such a simple-minded approach to weed control will offer at best short-term relief to growers, and even then only at the cost of sharply increased use of more toxic herbicides, with associated adverse impacts on the environment and public health. In the medium to longer-term, Nature will evolve clever responses to the chemical onslaught accompanying multiple-HR crop systems in the form of multiple herbicide-resistant weeds. Real solutions to resistant weeds, as opposed to temporary fixes, will have to involve a renewed commitment to integrated approaches that prioritize non-chemical means of weed control.[41]

Weed resistance is an evolutionary phenomenon. Frequent, repeated use of an herbicide selects for the preferential survival of those initially rare individuals with the genetic predisposition to survive its application. Over time, the resistant individuals propagate and gradually supplant susceptible weeds, resulting in a resistant weed population. The rate of evolution is critically dependent on the "selection pressure." The more frequently an herbicide is used, the more rapidly a resistant weed population will evolve.

Weeds have evolved many different mechanisms for surviving the application of herbicides. The best studied are so-called "target-site" alterations in the enzyme whose activity is normally blocked by the herbicide.[42] Disablement of the enzyme, which performs some critical function in the plant, results in the death of the normal weed. The target-site alteration makes the enzyme immune to the herbicide, conferring resistance on the weed. If the herbicide is regarded as a key and the target enzyme as a lock, the normal susceptible weed is killed when the key fits and opens the lock; the resistant weed has evolved an altered lock that the herbicidal key no longer opens. Target-site alterations normally confer resistance only to herbicides (one to many) that have the same "mode of

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Monsanto (2010b). "Monsanto Announces Record 11 Project Advancements in Annual Research and Development Pipeline Update," News Release, Jan 6, 2010.
http://monsanto.mediaroom.com/index.php?s=43&item=788.

[39] See USDA's list of GE crops pending nonregulated status at
http://www.aphis.usda.gov/biotechnology/not_reg.html, last updated August 20, 2010.

[40] Green et al (2007). "New multiple-herbicide crop resistance and formulation technology to augment the utility of glyphosate," Pest Management Science 64(4): 332-9.

[41] PSU (2010). "Suppressing Weeds Using Cover Crops in Pennyslvania," Pennsylvania State University, College of Agricultural Sciences, Agricultural Research and Cooperative Extension, 2010.

[42] For a recent review, see: Powles, S.B. & Q. Yu (2010). "Evolution in Action: Plants Resistant to Herbicides," *Annu. Rev. Plant Biol.*, 61: 8.1–8.31.

action."[43] Each "mode of action" (corresponding to a family or class of herbicides) represents a key that opens a particular lock.[44] Use of another herbicide with a different mode of action is usually effective in killing these types of weed.

A weed may also become resistant by evolving the ability to generate many-fold more copies of the target enzyme than are normally produced. In this case, the usual dose of the herbicide is only able to shut down a certain small proportion of the much more numerous enzyme molecules, while the others continue to function, allowing the thereby resistant weed to survive.[45] In terms of the key-lock analogy, the herbicide still fits the lock, but there are not enough herbicidal keys to open the more numerous locks.

Weeds may also evolve the ability to prevent or minimize internal movement of the herbicide, once absorbed by the plant, to the tissues (e.g. roots) it must reach to exert its killing effect, a mechanism known as reduced translocation. Still another mechanism involves reduced absorption of the herbicide, for instance via leaves with a thicker or tougher cuticle.[46] In these cases, the herbicide is unable to reach the lock (or not in sufficient quantities) to open it and so kill the weed.

In all of these cases, switching to an herbicide with a different mode of action will often provide control, at least for a time, though as discussed further below there are complications.

Another different class of resistance mechanisms is called "metabolic degradation" or "enhanced metabolism." Weeds with this form of resistance have the ability to degrade or metabolize the herbicide into a form that is not toxic to the plant. Interestingly, this mechanism often utilizes the plant's natural repertoire of detoxification enzymes, and involves several classes of enzyme that are quite similar to those present in the livers and other tissues of mammals, where they perform a similar detoxification function. Weeds that evolve resistance via metabolic degradation often have the ability to detoxify herbicides from several different families with different modes of action, making them particularly difficult to control. Powles and Yu (2010), in the paper already cited, note that the P450 class of detoxification enzymes represent "a very threatening resistance mechanism, because P450 enzymes can simultaneously metabolize herbicides of different modes of action, potentially including never-used herbicides."

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[43] For weeds resistant to different modes of action, see links under "Herbicide site of action" at http://www.weedscience.org/In.asp. Note that weeds highlighted in red with "Multiple – 2, 3, 4 or more MOAs" indicate multiple herbicide resistant weed populations that withstand herbicides from the specified number of herbicide families (MOAs = modes of action).

[44] The reality is more complicated. Each herbicide family, corresponding to a distinct mode of action, is actually comprised of several to dozens of active ingredients with slightly differing versions of the same basic key which all open the same lock. Resistant weeds may have resistance to all or in some cases only some members of herbicide family. In terms of our analogy, the lock may be altered such that none of the keys in a particular family open it, or in such a way that some keys do and others do not fit it.

[45] A population of the most damaging glyphosate-resistant weed, Palmer amaranth, recently evolved this mode of resistance. See: Gaines, T.A. et al (2010). "Gene amplification confers glyphosate resistance in Amaranthus palmeri," PNAS 107: 1029-34.

[46] For a recent review, see: Powles & Yu (2010), op. cit.

It is extremely important to observe that in most cases of weed resistance, the mechanism involved remains unknown. It requires extremely sophisticated molecular analysis as well and lengthy greenhouse testing to ascertain the mechanism of resistance in any particular case. And weed scientists are rapidly discovering that some weed populations possess two or more mechanisms of resistance to a single herbicide family, each lending only limited resistance, but together offering higher and more threatening levels.[47] Nature's evolution of weed resistance to herbicides takes quite ingenious turns,[48] and has far outpaced our technical capacities to ascertain the causes. This becomes clearer when one considers the vast numbers of resistant weeds in the world today.

According to the latest counts, over 400,000 fields in the world are infested with 348 herbicide-resistant biotypes of 194 different weed species.[49] A biotype is a particular weed species-herbicide family combination. The number of resistant biotypes exceeds the number of resistant species because a particular weed species can have various populations resistant to different herbicide families. Thus, separate tall waterhemp populations with resistance to glyphosate alone, or to ALS inhibitors alone, represent two distinct herbicide-resistant biotypes of a single weed species. The considerable excess of biotypes to species indicates that a number of weed species have different populations that are resistant to different herbicide modes of action.

The U.S. is by far the world leader in herbicide-resistant weeds, with 132 confirmed resistant biotypes infesting roughly 30 million acres.[50] Second place belongs to Australia, with just 54 resistant biotypes.[51] The most extensive populations of resistant weeds in the U.S. involve three major herbicide modes of action: resistance to photosystem II inhibitor class herbicides (chiefly the triazine class), which emerged chiefly in the 1970s; resistance to ALS inhibitor family herbicides, which evolved mainly in the 1980s and early 1990s when these herbicides were most heavily used; and resistance to glyphosate, which has evolved in dramatic fashion over just the past decade.[52]

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[47] Dinellli, G. et al (2006). "Physiological and molecular insight on the mechanisms of resistance to glyphosate in *Conyza Canadensis* (L.) Cronq. Biotypes," Pesticide Biochemistry and Physiology 86: 30-41.
[48] Gressel, J. & A.A. Levy (2006). "Agriculture: The selector of improbable mutations," PNAS 103: 12215-16.
[49] See http://www.weedscience.org/In.asp.
[50] Based on Center for Food Safety's compilation of data on herbicide-resistant weeds in the U.S. from the International Survey of Herbicide-Resistant Weeds (ISHRW), at www.weedscience.org, on November 30, 2010. 30 million acres is near the upper-bound estimate of 32.3 million acres, which is closer to reality than the lower bound estimate of 9.4 million acres. One indication of this is that a recent point estimate for acreage infested by glyphosate-resistant weeds alone, made by Dr. Ian Heap, who manages the ISHRW website, is 10.4 milllion acres, exceeding the lower-bound estimate for acreage infested by ***all*** herbicide-resistant weeds.
[51] http://www.weedscience.org/summary/CountrySummary.asp.
[52] Benbrook, C. (2009). Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Thirteen Years," The Organic Center, November 2009, pp. 12-13 and Figure 2.4. Note that acreage infested with glyphosate-resistant weeds as well as ALS inhibitor-resistant weeds has increased greatly since February of 2009, which is when the figures upon which the figure is based were compiled from ISHRW.

There are two basic pathways for weeds to evolve multiple herbicide resistance. In one pathway, weed populations ***accumulate*** resistance mechanisms, one by one, to different families of herbicides over years, while the other pathway (enhanced metabolism) involves resistance to several families of herbicides all at once.

The one-by-one pathway is made possible by the fact that weed populations, once they evolve resistance to a particular type of herbicide, often retain that resistance trait indefinitely. This is not necessarily the case, but it is often so. Weed scientists once assumed that an herbicide-resistant weed population would gradually disappear if farmers stopped applying the pertinent herbicide. This notion was based on the theoretical idea that in the absence of herbicide use, weeds ***without*** the resistance trait would always be more vigorous – grow faster and bigger, produce more seed and pollen – than resistant weeds. Thus, the latter would thrive only when the herbicide was used, but would be "outcompeted" by normal weeds in its absence. The theoretical underpinning of this idea is that the resistance trait imposes a "metabolic cost" or "fitness cost." That is, the resistant weed expends energy and resources to generate the resistance mechanism, and consequently has less to devote to growth and reproduction. According to this theory, the resistant weed, though of course favored when the herbicide is used, is less vigorous and fecund when not the herbicide is not applied.

As it turns out, this theory fits reality in some cases, but not in others. While some resistant weeds are indeed less "fit" in the absence of the pertinent herbicide's use, others are as just as fit or even more vigorous than their herbicide-susceptible brethren. As with mechanisms of resistance, weed scientists simply have not determined the fitness of the great majority of herbicide-resistant biotypes. Based on what little is known, however, we can make the following cautious generalizations about resistance to the three major modes of action presented above.

In general, weeds resistant to triazines tend to be less fit.[53] Some weeds resistant to ALS inhibitors exhibit lesser fitness, but others appear to have equivalent or even greater fitness than susceptible weeds.[54] Since glyphosate-resistant biotypes have emerged rapidly over just the past decade, in most cases their fitness has not been tested, and remains unknown. Given the importance of glyphosate in world agriculture, and the rapid emergence of glyphosate-resistant (GR) biotypes, elucidation of the fitness of GR weeds should be a top research priority.[55] Below, we discuss recent research that addresses this question.

The fitness of a resistant weed population helps determine how well it thrives in situations where farmers stop using the pertinent herbicide. Where fitness costs obtain, the resistant weed population will subside. Where there is no fitness cost, or indeed the resistant weed

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[53] Gronwald, J.W. (1994). "Resistance to photosystem II inhibiting herbicides," in: Powles, S.B. & J.A.M. Holtum, eds., *Herbicide Resistance in Plants: Biology and Biochemistry,* Ann Arbor, MI, Lewis, 1994.
[54] Tranel, P.J. & T.R. Wright (2002). "Resistance of weeds to ALS-inhibiting herbicides: what have we learned?" Weed Science 50: 700-712. Further examples are discussed below.
[55] Vila-Aiub, M.M. et al (2009). "Fitness costs associated with evolved herbicide resistance alleles in plants," New Phytologist 184: 751-767.

is more vigorous, ending use of the pertinent herbicide will do nothing to reduce resistant populations. In these cases, resistant weed populations may will persist indefinitely or perhaps even increase in scope even when the herbicide is not used.

Another important factor is the herbicide regime used by farmers. While we often think simplistically of farmers switching to a new mode of action when afflicted with weeds resistant to a particular herbicide, the reality is more complex. Often, herbicide A to which one or several weeds have evolved resistance will still be effective in controlling other troublesome weed species. In these cases, a common response of farmers is to supplement herbicide A with herbicide B rather than stop using A altogether. Thus, weed populations that have evolved resistance to A will continue to be exposed to it, and will continue to have an advantage over their susceptible brethren. Even if there is a fitness cost to herbicide A resistance, weeds resistant to it will continue to be favored.

The hope, of course, is that herbicide B will save the day by killing off weeds resistant to A. This forms the basis of the agrichemical -biotechnology industry's strategy of introducing multiple-herbicide resistant crops. And this will sometimes be an effective strategy. However, here too the reality is more complex. In those cases where the population of weeds resistant to A is small, the supplementation (or switching) strategy has a greater chance of success. However, this strategy is more likely to fail with larger resistant weed populations, for the following reason.

The larger the population of weeds resistant to herbicide A, the more likely that there exists among them individual weeds that have the rare genetic predisposition that confers resistance to herbicide B. Suppose that a small population of herbicide A-resistant weeds numbers 1,000, while a large population has 1 million individual plants. If on average only one in a million weeds are resistant, it is unlikely that the small population harbors one, while quite likely that the larger one does. It's essentially a numbers game, equivalent to tickets in a lottery. The small weed population is equivalent to buying just a few lottery tickets, while a large population corresponds to buying many tickets. The likelihood that the A-resistant population has a "winning ticket" (an individual with resistance to B as well as A) increases with its size. Winning the lottery, of course, is precisely what one wants to avoid in this case.[56]

What this means is that when a farmer either switches from herbicide A to herbicide B, or supplements A with B, he may well select for weeds that have resistance to ***both*** herbicides. This is the pathway by which weed populations accumulate resistance, one by one, to different herbicide modes of action.

This is the theory, and of course theory (as we have seen above with fitness) can be wrong. What do the facts on the ground tell us? One fact is that multiple herbicide-resistant weed populations are on the rise in the U.S., and have increased sharply over just the past three years. This is depicted in the table below, which is based on data compiled by Center for

[56] This lottery analogy is borrowed (and adapted) from Iowa State University weed scientist Bob Hartzler. See http://www.weeds.iastate.edu/mgmt/2004/twoforone.shtml.

Food Safety on resistant weeds from the best available source, the International Survey of Herbicide-Resistant Weeds (ISHRW).[57] The ISHRW is an online database that records populations of herbicide-resistant weeds, and is supported by agrichemical-biotechnology companies and academic weed scientists. Note that both the number of sites and acreage infested figures are given in ranges due to the difficulty of estimating the precise geographic extent of resistant weed populations. While most weed biotypes in the U.S. and the world today still have confirmed resistance to just one mode of action, the table below demonstrates a disturbing trend to proliferation of multiple herbicide-resistant (MHR) weed populations.

Data on Populations of Multiple Herbicide-Resistant Weeds in the U.S Over the Past Three Years

Date Compiled	No. of Species	No. of Populations	No. of States	Sites (min.)	Sites (max.)	Acreage (min.)	Acreage (max.)
11/21/07	11	20	12	679	1,459	25,829	245,755
11/30/10	14	32	15	1,016	3,078	127,799	1,258,605
% increase	27%	60%	25%	50%	111%	395%	412%

As the table shows, the number of MHR populations has increased by 60%, from 20 to 32, since November 2007. More concerning is the increase in the aggregate number of sites and acreage infested by these MHR populations. The number of sites infested has increased by half to more than double over the past three years, while the acreage infested has increased by a still more troubling 400%.

Two populations of MHR weeds that have emerged since November 2007 are resistant to glyphosate and paraquat. However, the most prevalent MHR weeds resist applications of ALS inhibitors and/or glyphosate. ALS inhibitor-resistant weeds emerged primarily in the 1980s and early 1990s following the introduction of herbicides with this mode of action in 1982. The fact that many weeds resistant to this mode of action have no loss of fitness (and in some cases have enhanced fitness) means that their populations have tended to persist or increase even as farmers made a large scale switch from reliance on them to use of glyphosate in tandem with the adoption of glyphosate-resistant Roundup Ready crops beginning in 1996. Many populations of ALS inhibitor-resistant weeds are also extremely large, infesting from hundreds of thousands to millions of acres. Two populations (in Missouri and Illinois) infest anywhere from 2 to 5 million acres each.

Over the past 14 years, glyphosate has largely displaced ALS inhibitors on the three crops – soybeans, cotton, and to a lesser extent corn – where Roundup Ready varieties have become predominant. These are also the three crops that receive the bulk of herbicides applied in U.S. agriculture as a whole. Consequently, it is no surprise that the majority of weeds evolving resistance over the past decade have become resistant to glyphosate. As with ALS inhibitors, glyphosate-resistant weed populations are often large, with several infesting hundreds of thousands to millions of acres.

As noted above, there has been a sharp rise in populations resistant to both ALS inhibitors and glyphosate. In November 2007, ISHRW recorded just 3 populations of two species of

[57] www.weedscience.org.

weed infesting at most 10,600 acres that were dual resistant to glyphosate and ALS inhibitors. By November 2010, just three years later, there were 7 populations of five species of weeds with dual resistance to these two modes of action, and they infested hundreds of thousands to as much as 1 million acres. This represents from 10-fold to 100-fold more infested acreage. The most extensive population of these weeds (tall waterhemp in Missouri) also resists a third mode of action, PPO inhibitors,[58] that are otherwise being relied upon by growers to combat resistance to glyphosate and ALS inhibitors. Tall waterhemp has a demonstrated ability to evolve resistance to two, three or more herbicide modes of action, and is for that and other reasons particularly feared.[59] University of Illinois weed scientists recently sounded the alarm about multiple herbicide-resistant tall waterhemp (*Amaranthus tuberculatus*) in their state and in Missouri:

> "Herbicide resistance in *A. tuberculatus* appears to be on the threshold of becoming an unmanageable problem in soybean."[60]

Noting that glufosinate is one of the few remaining options for control of late season waterhemp, they fear its loss to resistance as well:

> "Furthermore, on the basis of *A. tuberculatus's* history, there is no reason to expect it will not evolve resistance to glufosinate if this herbicide is widely used. If this happens, and no new soybean postemergence herbicides are commercialized, ***soybean production may not be practical in many Midwestern fields***." (emphasis added)

The emergence of dual resistance to glyphosate and ALS inhibitors fits the model of one-by-one accumulation of resistances presented above. Weeds initially evolved ALS inhibitor resistance in the 1980s and 1990s. Because many of these populations have no apparent loss of fitness, they have persisted into this decade; because they tend to be large, there existed among them weeds which had the rare genetic predisposition to survive glyphosate application. Massive use of glyphosate with Roundup Ready crops beginning in 1996 then fostered evolution of the dual-resistant biotypes.

To make matters still worse, a recent study of the most prevalent glyphosate-resistant weed species, horseweed, suggests that it has fitness equal to or greater than glyphosate-susceptible horseweed (at least in California), and that the glyphosate-resistant populations appear to be expanding whether or not glyphosate is applied to them.

> "In a survey conducted in 2006 and 2007, the majority of horseweed plants sampled in the southern SJV [San Joaquin Valley] were GR [glyphosate-resistant], regardless of nearby cropping systems (Hanson et al. 2009), suggesting the possibility that increased fitness may have contributed to the very rapid expansion in the range of

[58] See http://www.weedscience.org/Case/Case.asp?ResistID=5269.
[59] Tranel,P.J. (2010). "Introducing QuadStack waterhemp," Agronomy Day 2010, University of Illinois Extension.
[60] Tranel, P.J. et al (2010). "Herbicide resistances in Amaranthus tuberculatus: a call for new options," Journal of Agricultural and Food Chemistry, DOI: 10.1021/jf103797n.

> the GR biotype. ... Observations of vigorous and productive GR horseweed, regardless of whether it is growing in treated or untreated areas, suggests that the GR horseweed in California may be more competitive than the glyphosate-susceptible (GS) biotype in addition to being resistant to the most commonly used herbicide in orchards, vineyards, and adjacent noncrop areas (Shrestha, personal observation)."[61]

Still more troubling are the results of recent research on horseweed populations in Indiana and Ohio variously resistant to glyphosate alone, to ALS inhibitors alone, or to both classes of herbicides. The authors of this study reported that all three types of resistant horseweed displayed equal fitness to susceptible horseweed, as measured by "growth and seed production potential." They further warn that these populations are likely to persist and even increase in range with continued use of glyphosate and ALS inhibitors – and would be unlikely to "disappear" even if the growers were to stop using them. This latter possibility is unlikely, given the fact that these two modes of action are very commonly used to control many different weed species beyond horseweed in their region.

> "…. we conclude that horseweed populations composed of biotypes with single resistance to glyphosate and ALS-inhibiting herbicides, or multiple resistance to glyphosate + ALS-inhibiting herbicides have similar growth and seed production potential. Furthermore, the variation within these herbicide-resistant populations following exposure to herbicides would suggest that repeated applications will only increase the ability of these populations to compete and reproduce following repeated applications of the same herbicide or combination of herbicides. ... To control these herbicide-resistant horseweed populations, and to offset the evolution of more herbicide-resistant weeds, multiple integrated weed management practices need to be implemented with the idea that resistant biotypes will not just disappear after growers stop the application of these herbicide modes of action."[62]

Authors from the same team have also done several studies showing the clear potential for horseweed to evolve resistance to 2,4-D.[63] They note that:

> "Multiple-resistant and cross-resistant horseweed populations have evolved to various combinations of the previous herbicide modes of action in Israel, Michigan, and Ohio (Heap 2009), providing evidence for the plasticity of this weed."[64]

Importantly, their studies of potential 2,4-D resistance in horseweed have been driven by concern over the advisability of relying on some of the new herbicide-resistant crops, such

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[61] Shrestha, A. et al (2010). "Growth, Phenology, and Intraspecific Competition between Glyphosate-Resistant and Glyphosate-Susceptible Horseweeds (*Conyza canadensis*) in the San Joaquin Valley of California," Weed Science 58: 147-153.

[62] Davis, V.M. et al (2009). "Growth and Seed Production of Horseweed (*Conyza canadensis*) Populations Resistant to Glyphosate, ALS-Inhibiting, and Multiple (Glyphosate + ALS-Inhibiting) Herbicides," Weed Science 57: 494-504.

[63] Kruger, G.R. et al (2008). "Response and Survival of Rosette-Stage Horseweed (*Conyza canadensis*) after Exposure to 2,4-D," Weed Science 56: 748-752.

[64] Kruger, G.R. et al (2010). "Growth and Seed Production of Horseweed (*Conyza canadensis*) Populations after Exposure to Postemergence 2,4-D," Weed Science 58: 413-419.

as the 2,4-D and dicamba-resistant varieties mentioned above. Note that 2,4-D and dicamba are both "growth regulator" type herbicides:

> "With the impending commercialization of 2,4-D- and dicamba-resistant crops, it appears that additional options for control of glyphosate-resistant annual broadleaf weeds will be available. However, growth regulator herbicide-resistant technologies ***may not provide long-term solutions*** if resistant or tolerant populations currently exist or if populations become resistant under selection pressure from overreliance on growth regulators for broadleaf weed management."[65]

The implications of these various studies and data are clear. Weeds – including some of the most agronomically damaging and costly species like horseweed and tall waterhemp – have demonstrated the ability to evolve resistance to single modes of action as well as multiple herbicides. The single-resistant and in some cases dual-resistant weeds often suffer no "fitness cost," and thus their populations are likely to persist indefinitely, rather than conveniently "disappear" if farmers were to stop using them. The persistence of single- and multiple herbicide-resistant weed populations means that switching to, or supplementation with, new modes of action like 2,4-D and dicamba – in association with crops engineered with resistance to them – may backfire. While short-term relief is possible, these new 2,4-D and dicamba-resistant crops "may not provide long-term solutions..." if growers rely excessively on them. Rather, the introduction of multiple-herbicide resistant crops is quite likely to foster increasingly costly and damaging populations of weeds resistant to ever more herbicides.

The all-at-once pathway of herbicide-resistance is also concerning. As noted above, metabolic degradation mechanisms employing the plant's natural detoxification systems can evolve to confer resistance to multiple herbicides at one time – and potentially even to herbicides that have never before been used. At present, this mechanism of weed resistance has been observed mostly in grass-type weeds in Europe and Australia. Powles and Yu (2010) report 11 weed species that have the P450-mediated herbicide degradation mechanism alluded to above. Of these species, populations of blackgrass (*Alopecurus myosuroides*) and rigid ryegrass (*Lolium rigidum*) are among the worst, with resistance to multiple herbicides from three and four different herbicide families, respectively.[66] There have thus far been few reports of weeds with this mechanism of resistance in the U.S.,[67] though further investigations may reveal others.

The rapid increase in the number of weed populations resistant to glyphosate and to multiple herbicides as well as the acreage they infest poses serious problems for U.S. agriculture. Agronomists are wary of the agrichemical-biotechnology industry's preferred response to this problem – introduction of new crops resistant to older, more toxic herbicides, often in stacked versions conferring resistance to multiple herbicides. While

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[65] Ibid.

[66] Powles, S.B. & Q. Yu (2010). "Evolution in Action: Plants Resistant to Herbicides," *Annu. Rev. Plant Biol.*, 61: 8.1–8.31, Table 4.

[67] Park, K.W. et al (2004). "Absorption, translocation, and metabolism of propoxycarbazone-sodium in ALS-inhibitor resistant *Bromus tectorum* biotypes," Pesticide Biochemistry and Physiology 79: 18-24.

new technologies may provide some short-term relief, it will come only at the cost of increased herbicidal pollution of the environment, harm to human health, and greatly increased weed control costs for farmers. In the medium to longer term, Nature is likely to win this chemical arms resistance race between crops and weeds.

Do you know of any specific health threats presented by any of the herbicide resistant crop systems under development?

As noted above, two of the leading herbicide-resistant crop systems involve resistance to 2,4-D and dicamba. According to Pennsylvania State University weed scientist Dr. Dave Mortensen, widespread deployment of these crop systems will likely lead to a substantial increase in the use of these herbicides in U.S. agriculture. In testimony before this Subcommittee on July 28, 2010, Dr. Mortensen estimated that herbicide use on soybeans would increase by 70% within three years of introduction of 2,4-D and dicamba-resistant soybeans, assuming rapid adoption,[68] an increase of roughly 55 million lbs.[69]

Increased use of these herbicides, especially at that magnitude, would have adverse impacts on the environment, public health, and in particular the health of farmers.

The toxicity of 2,4-D (dichlorophenoxyacetic acid) has been exhaustively reviewed in a petition by public interest scientists to EPA requesting that the herbicide's registration be cancelled.[70] Ingestion or inhalation of 2,4-D has adverse effects on the nervous system – loss of coordination, limb stiffness, stupor, coma. A growing body of evidence points to 2,4-D as a carcinogen. Studies in the U.S., Italy, Canada, and several other countries link 2,4-D exposure to non-Hodgkin's lymphoma, a cancer of the immune system. Studies of farm workers exposed to 2,4-D revealed higher than normal rates of birth defects in their children. 2,4-D is also a mutagen and an endocrine disruptor, and can be contaminated during the production process with the even more toxic compound dioxin, which is highly carcinogenic, weakens the immune system, decreases fertility, and causes birth defects.[71] 2,4-D is banned in Norway.

Dicamba is a chlorinated benzoic acid herbicide similar in structure and mode of action to 2,4-D, and is used in both agriculture (e.g. corn, wheat) and on lawns.[72] In 1992, the National Cancer Institute (NCI) found that farmers exposed to dicamba were twice as likely

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[68] Mortensen, D. (2010). See http://oversight.house.gov/images/stories/Hearings/Domestic_Policy/2010/072810_Superweeds/072610_David_Mortensen_Testimony_072810.pdf.

[69] Mercer, D. (2010). "Roundup resistant weeds pose environmental threat," Associated Press, June 21, 2010. http://www.usatoday.com/tech/science/environment/2010-06-21-roundup-weeds_N.htm

[70] Comments to EPA on its 2,4-D Risk Assessment, Docket ID No OPP-2004-0167, submitted by a coalition of public health groups, including Natural Resources Defense Council and Beyond Pesticides, August 23, 2004.

[71] Beyond Pesticides (2004). 2,4-D: chemicalWATCH Fact Sheet, updated July 2004, Beyond Pesticides. http://www.beyondpesticides.org/pesticides/factsheets/2,4-D.pdf.

[72] Cox, C. (1994). "Dicamba Factsheet," *Journal of Pesticide Reform* 14(1): 30-35.

to contract non-Hodgkin's lymphoma.[73] A subsequent NCI study reported associations between dicamba exposure and higher incidence of lung and colon cancer in pesticide applicators.[74] Researchers have also found a 20% percent inhibition of the nervous system enzyme acetylcholinesterase in a group of certified pesticide applicators whose only common pesticide used was dicamba.[75] Exposure to organophosphate insecticide residues in food has recently been linked to increased rates of attention-deficit/hyperactivity disorder in children, and the presumed mechanism is inhibition of acetylcholinesterase, an enzyme essential for normal brain development.[76] Dicamba is moderately persistent in soil and water, and is frequently found contaminating ground water supplies.[77] Pregnant mice that ingested drinking water spiked with low doses of a commercial herbicide product containing dicamba, 2,4-D and mecoprop had reduced litter size, suggesting that this herbicide mixture may have developmental toxicity.[78] A study of the frequency of sister chromatid exchanges (SCEs) and cell-cycle progression assays revealed that high doses of dicamba can damage DNA, leading the study authors to warn that dicamba is a "potentially hazardous compound to humans."[79]

Dicamba is also highly volatile, and under the right conditions (hot days, no rainfall) can revolatilize after application and drift to damage neighboring crops or plants bordering fields.[80] This drift can cause significant economic damage to other farmers, and also destroy habitat for pollinators and other beneficial insects.[81] The greatly increased use of dicamba to be expected with dicamba-resistant crops will likely exacerbate these adverse impacts. South Africa completely prohibited use of dicamba in some districts, and banned aerial application in others.[82]

2,4-D-resistant crops may pose a new food safety risk beyond the risks attributable to the increased use of 2,4-D to be expected with its adoption. First, one must understand that monocot plants (cereal crops like corn) have a natural tolerance to low levels of 2,4-D, facilitating the use of this pesticide on major field crops like wheat and corn. Numerous

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[73] Cantor, K.P. (1992). "Pesticides and other agricultural risk factors for non-Hodgkin's lymphoma among men in Iowa and Minnesota," *Cancer Res.* 52: 2447-2455.
[74] Samanic, C. et al (2006). "Cancer Incidence among Pesticide Applicators Exposed to Dicamba in the Agricultural Health Study," *Environmental Health Perspectives* 114: 1521-1526.
[75] Potter, WT, et al. (1993). "Radiometric assay of red cell and plasma cholinesterase in pesticide appliers from Minnesota." *Toxicology and Applied Pharmacology* 119: 150-155.
76 Bourchard, M. F. et al (2010). "Attention-Deficit/Hyperactivity Disorder and Urinary Metabolites of Organophosphate Pesticides," Pediatrics 2010; 125:e1270–e1277.
[77] Thurman, E.M. et al (2003). "Regional Water-Quality Analysis of 2,4-D and Dicamba in River Water Using Gas Chromatography-Isotope Dilution Mass Spectrometry," *International Journal of Environmental Analytical Chemistry* 79: 185-198.
[78] Cavieres, M.F., J. Jaeger & W. Porter (2002). "Developmental Toxicity of a Commercial Herbicide Mixture in Mice: I. Effects on Embryo Implantation and Litter Size," *Environmental Health Perspectives* 110: 1081-1085.
[79] Gonzalez, N.V. et al (2006). "Genotoxicity analysis of the phenoxy herbicide dicamba in mammalian cells in vitro," *Toxicology in Vitro* 20: 1481-87.
[80]Hartzler, B. (2004). "Dicamba Volatility," Iowa State University posting, July 24, 2001, http://www.weeds.iastate.edu/mgmt/2001/dicambavolatility.htm
[81] Mercer, D. (2010, op. cit.
[82] "Banned and restricted substances in the republic of South Africa." April 22, 2008. Accessed online July 19, 2010. http://www.nda.agric.za/act36/Banned%20and%20restricted.htm.

studies have examined precisely how 2,4-D is metabolized by non-genetically engineered plants so as to render it non-toxic to the plant. 2,4-D-resistant plants incorporate a bacteria-derived gene that metabolizes 2,4-D in a different way, transforming it into 2,4-dichlorophenol (2,4-DCP). 2,4-DCP is not produced, or only in very small amounts, when naturally tolerant plants metabolize 2,4-D.

2,4-DCP is a chlorophenol compound that is individually listed by EPA in its toxics release inventory of toxic chemicals.[83] The European Union also lists 2,4-DCP as a hazardous substance. Animals dosed with high levels of chlorophenols in their food or drinking water experienced adverse liver and immune system effects, and did not gain as much weight as control animals. Some studies have shown increased risk of cancer, as well as acne and liver damage, among workers in pesticide plants that make chlorophenols, though it is not clear whether the effects were due to chlorophenols or other chemicals.[84]

Dow AgroSciences uses 2,4-DCP as a raw material to manufacture pesticides. In a material safety data sheet for 2,4-DCP,[85] Dow notes that exposure of just 1% of a worker's body (an area the size of the palm of a hand) to molten 2,4-DCP may cause death. Dow's industrial hygiene guideline for 2,4-DCP is 1 part per million, skin. Dow reports that animal testing has revealed that 2,4-DCP has adverse effects on blood forming organs (bone marrow & spleen), kidney and liver; that 2,4-DCP may be contaminated by the more toxic 2,4,6-trichlorophenol (known to the State of California to cause cancer); and that this contaminant (present at a level of 0.1% in current samples) may explain the inconclusive results in carcinogenicity tests on animals. Dow further notes that in-vitro genetic toxicity (mutagenicity) studies with 2,4-DCP were negative in some cases and positive in other cases, and that it found no relevant information with respect to possible reproductive effects from 2,4-DCP exposure. Dow found that 2,4-DCP is moderately toxic to aquatic organisms on an acute basis (LC50 or EC50 between 1 and 10 mg/L in most sensitive species tested).

French scientists conducted experiments to determine whether the 2,4-DCP generated by transgenic, 2,4-D-resistant plants after spraying with 2,4-D would be broken down into less toxic compounds. They found that the basic structure of the 2,4-DCP molecule remained intact. The French team concluded that 2,4-D-resistant plants sprayed with 2,4-D "may not be acceptable for human consumption."[86] They further point to the potential for 2,4-DCP

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83 EPA (1999). Emergency Planning and Community Right-to-Know Section 313: List of Toxic Chemicals within the Chlorophenols Category, Environmental Protection Agency, June 1999 (Technical Update November 2005).

84 USDHHS (1999). "Toxicological Profile for Chlorophenols," Agency for Toxic Substances and Disease Registry, Public Health Service, US Dept of Health and Human Services, July 1999.

85 Dow (2006). 2,4-Dichlorophenol Material Safety Data Sheet, Product Code: 20636, MSDS Number: 000715. Dow AgroSciences LLC, Effective Date: 7-Sept-06.

86 Laurent, F. et al (2006). "Metabolism of [14C]-2,4-dichlorophenol in edible plants," Pest Management Science 62: 558-564.

residues in foods derived from 2,4-D resistant plants to be transformed *in vivo* into more highly chlorinated compounds that have greater toxicity.[87]

BASF is awaiting USDA deregulation of genetically engineered, imidazolinone-resistant soybeans (BPS-CV127-9).[88] Imazethapyr, one of the most widely used of the imidazolinone class of herbicides (a form of heterocyclic aromatic amine), has been associated with increased risk of bladder and colon cancers in farmers who use this herbicide.[89]

Could you elaborate on the external costs imposed on growers and the environment caused by the cultivation of herbicide-resistant crops?

As explained by Steve Smith in testimony before this Subcommittee on September 30, 2010, herbicide-resistant crops make it possible to apply large quantities of herbicides much later in the growing season than is possible otherwise. This facilitation of postemergence herbicide use means that neighboring growers will be vulnerable to crop injury from herbicide drift to a much greater extent than they were before HR crops were introduced. Costs incurred from crop injury by growers whose crops are not resistant to the pertinent herbicide are difficult to estimate, but could be substantial, especially in the case of a volatile herbicide like dicamba.

In order to defend their crops from herbicide drift damage, some and perhaps very many growers will purchase seed that is herbicide-resistant for defensive purposes, not because they want to make use of the trait and associated herbicide for weed control. In fact, this has already happened with Roundup Ready technology, and is happening now with Clearfield.

According to Arkansas weed consultant Ford Baldwin:

> "A lot of growers planted Roundup Ready corn in the beginning out of self defense. I looked at enough glyphosate drift on conventional corn to understand why. Most growers initially used conventional herbicides in the Roundup Ready corn. Over time though the progression was to glyphosate-based programs and we lost a lot of the benefit of what could have been a great resistance management tool."[90]

Growers who bought Roundup Ready corn "out of self defense" paid a substantial premium (technology) fee for a trait they did not want. This is an external cost imposed by the Roundup Ready crop system, as it is used in the real world. Mr. Baldwin's article, however, focuses on an analogous situation with another herbicide-resistant crop, Clearfield rice.

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[87] Wittsiepe, J. et al (2000). "Myeloperoxidase-catalyzed formation of PCDD/F from chlorophenols," Chemosphere 40: 963-968.

88 See petition 09-015-01p at http://www.aphis.usda.gov/biotechnology/not_reg.html.

[89] Koutros, S. et al (2009). "Heterocyclic aromatic amine pesticide use and human cancer risk: Results from the U.S. Agricultural Health Study," Int. J. Cancer 124: 1206-1212.

[90] Baldwin, F.L. (2010). "Herbicide drift damaging rice," Delta Farm Press, June 7, 2010. http://deltafarmpress.com/rice/herbicide-drift-damaging-rice-0607/.

Clearfield is a non-GE type HR crop, resistant to the imidazolinone class of herbicides of the ALS inhibitor family. Newpath is BASF's formulation of imazethapyr.

> "My university counterparts have received more Newpath drift calls than normal as well. At present, four out of every five requests to come to a field involve some problem with Newpath on conventional rice. Most involve drift, but there have also been several cases of miscommunication between neighbors, and also between farmers and applicators on whether a particular field was Clearfield or conventional rice.
>
> These situations are never good. They have led to more talk of "defensive" planting of Clearfield rice. While it is easy for the good doctor to sit at his desk and say that is a bad idea, I have looked at several fields this year where I must admit I couldn't blame the farmer for his thinking."

Baldwin is clearly sympathetic to the crop injury and losses incurred by growers of conventional corn (due to Roundup drift from Roundup Ready fields) and conventional rice (due to Newpath drift from Clearfield rice fields). Yet he is no enemy of either technology. On the contrary, he regards them as useful tools for farmers, but tools that are having unfortunate and costly impacts on those who choose not to use them.

But the real thrust of the article has to do with the difficulty of using these herbicide-resistant crop systems in a ***sustainable*** manner, which is exacerbated by the drift issue. Growers initially bought Roundup Ready corn for defensive reasons: "Over time though the progression was to glyphosate-based programs ***and we lost a lot of the benefit of what could have been a great resistance management tool.***" What is the "great resistance management tool" that was lost? First, it was growing conventional corn with "conventional" [non-glyphosate] herbicides. That is, growers who planted Roundup Ready soybeans or cotton and then rotated to conventional corn were practicing "resistance management" by not using glyphosate for at least one year in their rotations. When they began switching to Roundup Ready corn for defensive reasons, they continued at first to use non-glyphosate herbicides with it, retaining the resistance management benefit. However, eventually they switched over to glyphosate with RR corn, increasing selection pressure for glyphosate-resistant weeds.

While Baldwin does not elaborate, it was probably economics that drove this decision. When a farmer pays a hefty technology fee for an RR traited seed, it makes economic sense to make use of it through using inexpensive glyphosate, rather than mostly more expensive "conventional" herbicides. If they hadn't been forced for "defensive" reasons to buy more expensive Roundup Ready corn, they probably would have continued planting cheaper conventional corn, which entails using conventional herbicides, and provides a resistance-managing "break" from continual glyphosate use.

Baldwin sees the same thing happening with Clearfield rice.

> "Most weed scientists I know feel we are growing more Clearfield rice now than is sustainable over time – unless we get a breakthrough in new technology. As we

> continue to increase the acres, most likely we are shortening the life of the technology. ... If you plant every acre to Clearfield and continue to pound it with Newpath and Beyond, resistant barnyardgrass will be the most likely end result."

When adoption of these two HR crops – RR corn and Newpath rice – reached a certain tipping point, the crop-damaging drift that is a consistent feature of these HR technologies forced many other growers to unwillingly adopt them. This led to massive overreliance on the HR crop-associated herbicides, loss of the resistance management benefits provided by retaining a conventional crop in the rotation, and a spate of new herbicide-resistant weeds. The resistant weeds drive the demand for "new technology" in the form of a new herbicide or new herbicide-resistant crop – spurring yet another turn in the vicious spiral of increasing herbicide use and weed resistance. It's hard to imagine a more unsustainable technology than herbicide-resistant crop systems, at least as they are used in the real world, in the absence of regulation.

The only way to get off this pesticide treadmill is through integrated weed management that prioritizes non-chemical weed control measures. Unfortunately, mainstream American agriculture has been so thoroughly fixated on the chemical-only approach that most farmers, extension agents, and weed scientists have no clue where to begin. The silver lining in the HR weed epidemic may perhaps be that it is opening minds like that of Dr. Stanley Culpepper, weed scientist at the University of Georgia.

Culpepper is in the midst of a glyphosate-resistant pigweed epidemic that is rapidly making cotton-growing an impossible task in Georgia. In 2009, half of Georgia's one million acres of cotton had to be weeded by hand to remove this GR weed, at a cost of $11 million. Growers who until recently spent $25 per acre on weed control are now forced to spend $60 to $100 per acre. According to Culpepper: "We're talking survival, at least economically speaking, in some areas, because some growers aren't going to survive this."[91]

While Culpepper does not advocate giving up herbicides, he understands that the old approach of relying upon them exclusively is doomed to fail. Culpepper now recommends deep tillage to bury the resistant pigweed seed so that it will not sprout, which can reduce seed germination by up to 50%. He also recommends the planting of heavy cover crops like rye to provide a thick mat between crop rows that likewise reduces weed seed germination by as much as 50%. Together, the two techniques reduce the emergence of resistant pigweed that actually emerges, but up to 80%. The much reduced populations of weeds (resistant or not) that do emerge can then be managed with much lesser quantities of herbicides.

While Dr. Culpepper appears to be a recent convert to the virtues of cover cropping and other non-chemical modes of weed control, other scientists have been working to improve and encourage adoption of such practices for many years, mostly without recognition and

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[91] Haire, B. (2010). "Pigweed threatens Georgia cotton industry," Southeast Farm Press, July 6, 2010. http://southeastfarmpress.com/pigweed-threatens-georgia-cotton-industry.

with far too little support from our pesticide-friendly U.S. Dept. of Agriculture. Dr. Adam Davis recently published a study showing the effectiveness of the "cover crop roller-crimper" for use in no-till soybean cultivation.[92] The roller-crimper is a heavy, flanged cylinder that is attached to a tractor and rolled over a cover crop like rye in the spring to kill it. The killed cover crop forms a heavy mat into which soybeans can be drilled, and which physically suppresses weed emergence, as discussed above. Some cover crops also exude allelopathic compounds into the soil that also inhibit the emergence of weeds.

Dr. Matt Liebman at Iowa State University has shown the great benefits to farmers from adopting more complex rotations involving three or more crops (including a winter cover crop or alfalfa), rather than the standard corn-soybean rotation.[93] In addition to decreasing use of (and expenditures on) synthetic nitrogen fertilizers by half to three-fourths, the more complex three- and four-year rotations reduced herbicide use by 76% and 82%, respectively, with weed suppression equivalent to the herbicide-intensive, conventional corn/soybean rotation, and yields that were equal or higher. These "low-external input" (LEI) systems were also more profitable than the conventional rotation, especially when considered in the absence of subsidies. Our perverted subsidy system, however, reduce the differences between the systems, and act as an impediment to adoption of such beneficial systems by American growers. A perhaps even more important factor, however, is the paucity of support to truly sustainable weed management systems such as this on the part of the U.S. Dept. of Agriculture, which like the major agrichemical-biotechnology firms is fixated on chemical-only approaches to weed control and farming in general.

We conclude by citing a very recent paper by Illinois agronomists, who are at ground zero of an extremely threatening outbreak of multiple herbicide-resistant tall waterhemp (*Amaranthus tuberculatus*). Patrick Tranel and colleagues have recently surveyed fields in Illinois and Missouri, and found a startingly high proportion of tall waterhemp populations to be resistant to glyphosate as well as one, two or in some cases even three additional herbicide modes of action.[94] Tall waterhemp is regarded as one of the most threatening weeds to soybean and to a lesser extent corn cultivation in the Midwest, particularly in Illinois and Missouri. Waterhemp populations with individuals resistant to only one herbicide mode of action are practically a thing of the past. The majority of populations now contain multiple-herbicide resistant plants. Tranel and colleagues state that:

> "Herbicide resistance in A. tuberculatus appears to be on the threshold of becoming an unmanageable problem in soybean."

They further warn that these weed populations will likely evolve resistance to glufosinate, one of the few postemergence herbicidal options available to growers afflicted with these multiple herbicide-resistant populations. This would occur with widespread deployment

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[92] Davis, A.S. (2010). "Cover-Crop Roller–Crimper Contributes to Weed Management in No-Till Soybean," Weed Science 58: 300-309.
[93] Liebman, M. et al (2008). "Agronomic and Economic Performance Characteristics of Conventional and Low-External-Input Cropping Systems in the Central Corn Belt," Agronomy Journal 100: 600-610.
[94] Tranel, P.J. (2010). "Herbicide resistances in Amaranthus tuberculatus: A call for new options," Journal of Agricultural and Food Chemistry, DOI:10.1021/jf103797n.

of glufosinate-resistant, LibertyLink soybeans, which at present are very little grown. If this happens, they warn, and no new soybean postemergence herbicides are commercialized:

> "Soybean production may not be practical in many Midwest U.S. fields."

The inability to economically cultivate the second most widely grown crop in America, a mainstay of Midwestern agriculture, would represent a huge cost imposed by unregulated use of HR crop systems on American farmers and U.S. agriculture as a whole. Clearly, USDA and land grant university agronomists must begin devoting serious attention to the sorts of sustainable, integrated weed control practices described above, which make non-chemical approaches a priority, and deemphasize the use of herbicides.

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October 15, 2010

Mr. Jay Vroom
President and CEO
CropLife America
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Dear Mr. Vroom:

In connection with the September 30, 2010 hearing of the Domestic Policy Subcommittee, entitled, "Are "Superweeds" an Outgrowth of USDA Biotech Policy? (Part II)", I hereby request that you provide answers in writing to the following questions for the hearing record.

1. Does the industry believe USDA has authority under the Plant Protection Act (codified at 7 U.S.C. § 7701 *et. seq.*) and its regulations to regulate GE crops so as to prevent pesticide-resistant pests (including herbicide-resistant weeds)?
2. Does the industry believe that U.S.E.P.A. has that authority under a different statute?
3. Can the industry point to any purely voluntary stewardship practices that have successfully prevented or contained the spread of glyphosate resistance in weeds on a broad basis involving many individual farmers?
4. What regulatory schemes are supported by the industry that would prevent harm to horticultural crops and landscapes growing in proximity to soybean fields, if Dicamba-resistant soy is deregulated by USDA?
5. What is the extent of glyphosate-resistance in weeds outside of the United States? Please provide a country-by-country assessment, in tabular form, of glyphosate-resistant weeds, in terms of glypohsate-resistant species by name and date of discovery, estimated number of acres of infestation, and date of commercialization of Roundup-Ready corn, soy or cotton (as is applicable).

Ranking member Jordan submits the following additional questions:

1. Do you think that introducing multiple modes of action that control weeds in different ways and appropriate herbicide management techniques can help address the challenge of herbicide-resistant weeds?

2. How quickly will the issue of herbicide-resistant weeds worsen in the absence of new technologies entering the marketplace?

The Oversight and Government Reform Committee is the principal oversight committee in the House of Representatives and has broad oversight jurisdiction as set forth in House Rule X.

We request that you provide written answers to these questions as soon as possible, but in no case later than **5:00 p.m. on October 30, 2010**.

If you have any questions regarding this request, please contact Jaron Bourke, Staff Director at (202) 225-6427.

Sincerely,

Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee

cc: Jim Jordan
Ranking Minority Member

CropLife ☆AMERICA☆

November 5, 2010

The Honorable Dennis J. Kucinich
Chairman, Domestic Policy Subcommittee
Committee on Oversight and Government Reform
U. S. House of Representatives

Dear Congressman Kucinich:

CropLife America (CLA) thanks you for the opportunity to provide testimony on September 30, 2010 during the Domestic Policy Subcommittee hearing entitled, "Are "Superweeds" an Outgrowth of USDA Biotech Policy? (Part II)". CropLife America is the leading trade association representing the U.S. crop protection industry and our members supply virtually all of the crop protection products used by American farmers. CropLife America's member companies, and members of our counterpart association at RISE[1], proudly discover, manufacture, register and distribute crop protection products for American agriculture, and specialty use products outside of agriculture, such as those used for public health protection and commercial pest management inside of homes and commercial buildings.

During the first hearing, CLA emphasized three major points that are essential to understanding weed resistance to herbicides and the need for best management practices to minimize the potential for resistance development:

- Herbicide resistance occurs naturally, and best management practices need to be applied at the farm level in ensuring that resistance development is avoided or delayed. Resistance is a scientific reality in virtually all biological systems.
- The market can and will facilitate the development and adoption of solutions to combat weed resistance in crop production to ensure production of safe, affordable, and plentiful food.
- The current regulatory framework for herbicides is robust.

As requested, below are our responses to questions for the hearing record.

1. **Does the industry believe USDA has authority under the Plant Protection Act (codified at 7 U.S.C. § 7701 *et. seq.*) and its regulations to regulate GE crops so as to prevent pesticide-resistant pests (including herbicide-resistant weeds)?**

Recognizing that CLA does not represent the crop protection industry on the specific matter of regulations for genetically engineered (GE) crops, CLA would consult the affected agencies for their interpretation of the laws granting them specific authorities. However, USDA has the authority under Part 340 of the Plant Protection Act to regulate

[1] Responsible Industry for a Sound Environment (RISE) – www.pestfacts.org

the introduction (importation, interstate movement, or release into the environment) of GE crops. Unlike crops genetically engineered to produce Bt proteins to control insects, herbicide-tolerant (HT) crops do not control weeds or any other pests. In addition to examining potential risks to plant health under the Plant Protection Act, APHIS assesses the potential effects of its actions on the quality of the environment under the authority of the National Environmental Policy Act.

Regulation of the herbicides that accomplish weed control is under the jurisdiction of EPA (see next question.) USDA and EPA work cooperatively as necessary to identify, develop, and approve best management practices for avoiding and mitigating pest resistance to pesticides.

2. Does the industry believe that U.S.E.P.A. has that authority under a different statute?

Recognizing that CLA does not represent industry on regulations for GE crops, CLA would consult the affected agencies for their interpretation of the laws granting them specific authorities. However, the safe use of pesticidal substances is regulated by the Environmental Protection Agency (EPA). GE insect-resistant crops may contain an introduced pesticidal substance also known as a plant-incorporated protectant (PIP) that is subject to review by EPA. EPA's regulatory process for PIPs includes rigorous environmental assessment. As mentioned earlier, USDA and EPA work cooperatively as necessary to identify, develop, and approve best management practices for avoiding and mitigating pest resistance to pesticides.

The use of pesticides in the U.S. is regulated by EPA under the Federal Insecticide, Fungicide, & Rodenticide Act (FIFRA; codified at 7 USC §136 *et seq.*) and selected provisions of the Federal Food, Drug, & Cosmetic Act (FFDCA; codified at 21 USC §301 *et seq.*; specifically 21 USC §346a). Implementing regulations are published in 40 CFR Parts 150 to 189. This authority can and does extend to resistance mitigation strategies. EPA reviews, approves, and regulates every statement and instruction that goes on the label of every pesticide and herbicide product, according to these laws and regulations. This responsibility is taken very seriously by EPA and pesticide registrants. State regulators and enforcement personnel are EPA's close partners in seeing that pesticide products carry the correct, valid labels and that farmers use them correctly.

3. Can the industry point to any purely voluntary stewardship practices that have successfully prevented or contained the spread of glyphosate resistance in weeds on a broad basis involving many individual famers?

In Arkansas, extension, academic, and government personnel, together with grower organizations have developed a strong program for management of glyphosate-resistant weed populations, focusing on "zero tolerance." Education and outreach efforts are extensive, and industry is fully cooperating. Member companies represented by the Industry's Herbicide Resistance Action Committee (HRAC) and CropLife America have monitored and researched the herbicide resistance issue on a global basis for 20 years,

cooperating closely with academia and government authorities in developing and implementing resistance management strategies. HRAC has been very active in the recent developments concerning glyphosate-resistant weeds.

In Arkansas, farmers are strongly encouraged to closely monitor all fields, acre by acre, row by row, following all herbicide treatments including glyphosate. Any weeds escaping control are to be removed, by spot treatment with other herbicides, by hoe, or by hand, if necessary. Other herbicides must be used in combination with or in place of glyphosate to control the resistant weeds. Other crops may be grown in rotation in subsequent growing seasons to facilitate a diversity of weed control practices. Harvesting equipment should be cleaned carefully before it leaves a field where resistant weeds are known or suspected, to avoid spreading them to other fields. Registrants are offering financial incentives to convince growers to employ best management practices, including using a competitor's product, when necessary.

Such extensive efforts are an example of progress in the fight against glyphosate-resistant weeds in Arkansas. Similar efforts tailored to local needs are in practice and under development in other affected Southern states. States not yet affected are watching closely and learning the lessons that can be implemented to avert losses.

4. **What regulatory schemes are supported by the industry that would prevent harm to horticultural crops and landscapes growing in proximity to soybean fields, if Dicamba-resistant soy is deregulated by USDA?**

EPA evaluates the potential off-site movement of an herbicide when deciding whether to register a product for a particular use and will require label instructions designed to minimize off-site movement. EPA-registered herbicides have been used successfully in agriculture for decades and farmers have extensive experience in managing off-site movement by strict adherence to label instructions and the application of best management practice. Industry supports pesticide applicator efforts to minimize off-site movement by providing education and training resources, and continued research and development of technologies to further reduce such movement.

5. **What is the extent of glyphosate-resistance in weeds outside of the United States? Please provide a country-by-country assessment, in tabular form, of glyphosate-resistant weeds, in terms of glyphosate-resistant species by name and date of discovery, estimated number of acres of infestation, and date of commercialization of Roundup-Ready corn, soy or cotton (as is applicable).**

CropLife America does not have the information requested on the global status of glyphosate resistance. However, CLA supports efforts by HRAC to compile reports of herbicide resistance to all herbicides worldwide.

Additional questions from Ranking Member Jordan are addressed below:

1. **Do you think that introducing multiple modes of action that control weeds in different ways and appropriate herbicide management techniques can help address the challenge of herbicide-resistant weeds?**

Yes, use of best management practices in concert with herbicides that have different modes of action is a component of integrated pest management broadly supported by public and private sector scientists. Use of multiple modes of action will reduce the impact of herbicide-resistant weeds. To avoid or delay the onset of resistance, growers need to be aware of and adopt best management practices. Information regarding best management practices and integrated weed management is available from multiple reliable sources including websites sponsored by the Weed Science Society of America (WSSA) and HRAC.

2. **How quickly will the issue of herbicide-resistant weeds worsen in the absence of new technologies entering the marketplace?**

Using a diversity of weed management options is important for managing weed resistance. New technologies provide growers with more options that make is easier to implement effective weed management in all cropping systems across the U.S. Adoption of biotechnology has not caused the rapid onset of resistance in weed species; appropriate use of a diversity of technologies is fundamental for reducing the impact of resistance.

The market can and will adopt solutions to combat weed resistance in crop production to ensure production of safe, affordable and plentiful food. Farming is a long-term investment, and growers will adapt their operations to succeed. They need the flexibility to manage their farm operations for the current season and for the future. That flexibility requires access to the tools that enable them to take care of their business interests and sufficient latitude in terms of how and when they are used. Growers are in the best position to know their fields, the weeds growing in them, and how to best manage their farm inputs. Such knowledge will enable them to make the best decisions on what tools to use, including crop protection products and biotech crop seed, considering relevant economic factors and their future management plans.

Weed control options will continue to be developed. Crop protection is a competitive business. If a weakness in a particular weed control option emerges, there will be other new or existing technologies that will seek to fill that void. The market favors maximization of the tools currently available. The development of new herbicides is an involved and expensive process. To make that investment worthwhile requires that the useful life of a product be extended as long as possible with available means. Some recent marketing programs have included manufacturer rebates for use of competitive products in combination with the manufacturer's product, in order to stem the onset of resistance. This is one example of how the market addresses the issue.

Thank you for the opportunity to provide this information. If we can be of further assistance, please contact Beau Greenwood, Executive Vice President, Federal Affairs (bgreenwood@croplifeamerica.org).

Sincerely,



Jay J. Vroom
President and CEO

cc. Jim Jordon, Ranking Minority Member

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BILL SHUSTER, PENNSYLVANIA

October 15, 2010

Mr. Steve Smith
Director of Agriculture
Red Gold, Inc.
P.O. Box 83
Elwood, IN 46036

Dear Mr. Smith:

In connection with the September 30, 2010 hearing of the Domestic Policy Subcommittee, entitled, "Are "Superweeds" an Outgrowth of USDA Biotech Policy? (Part II)", Representative Jim Jordan, Ranking Member, requests that you provide answers in writing to the following questions for the hearing record.

1. You testified that your company and growers faced over $1 million in cropping losses from glyphosate drift. Can you describe specifically what caused those alleged losses?
2. What losses have your growers experienced as a result of dicamba drift and revolatilization?

The Oversight and Government Reform Committee is the principal oversight committee in the House of Representatives and has broad oversight jurisdiction as set forth in House Rule X.

We request that you provide written answers to these questions as soon as possible, but in no case later than **5:00 p.m. on October 30, 2010**.

If you have any questions regarding this request, please contact Jaron Bourke, Staff Director at (202) 225-6427.

Sincerely,

Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee

cc: Jim Jordan
Ranking Minority Member

Premium Tomato & Food Products

P.O. BOX 83 . ELWOOD, IN 46036 . TEL (765)-754-7527 . FAX (765) 754-3230. www.redgold.com

October 19, 2010

Honorable Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee
2157 Rayburn House Office Building
Washington, DC 20515-6143

Dear Chairman Kucinich,

Thank you for the opportunity to reply to questions concerning my recent testimony about the effects to the Midwestern tomato industry by the release of dicamba tolerant soybeans during the Part II hearing entitled, "Are Superweeds an Outgrowth of USDA Biotech Policy?"

Question #1 referred to my testimony asserting over $1 million in cropping losses from glyphosate drift. I have attached a spreadsheet outlining our exact crop losses from all forms of drift and volatization for the last four cropping seasons and the eventual outcome of the losses. As you will see, several are still in litigation which is the reasoning behind my comments and requests that the makers of dicamba and the registrants of dicamba tolerant soybeans to immediately be financially responsible for losses.

Question #2 asks about our actual experiences as a result of dicamba drift and revolatization. As you will notice from the spreadsheet, we have had only one dicamba volatility issue in the last four years and it occurred early enough in the growing cycle that the field could be replanted, so the large losses to us the processor of not having fruit available and big yield losses to the grower were mitigated to a great degree. However, as my testimony said, the use of dicamba in our area is nearly non-existent because of the potential losses to soybeans. The important point is that revolatization is a known characteristic of dicamba and when sensitive crops are present, damage will occur, and as listed, we have had an actual case even with very little actual exposure.

I would be more than pleased to answer any further questions or explain any other statements that may arise.

Sincerely,

Steve Smith
(sent electronically)

Red Gold Drift Loss Summary 1997-2010

Year	Grower	Loss Total	Cause of loss	settlement outcome
2007	Gelfius Farms	$ 18,934.00	Acetochlor	still in litigation
2008	Janssen Brothers Farms	$ 24,915.13	glyphosate	still in litigation
	Morrin Farms	$ 14,570.44	glylphosate	still in litigation
	Lievens Brothers Farms	$ 702,197.77	glyphosate	still in litigation
	Keesling Farms	$ 18,660.00	2,4 d	settled in full
	Triple S Smith Farms	$ 137,126.57	glyphosate	settled in full
	Daily Farms	$ 63,085.82	glyphosate	settled at about 90%
	Associated Growers	$ 4,725.00	dicamba	no settlement, sprayer denied claim, able to replant
	Detling Farms	$ 3,306.09	glyphosate	settled in full
2009	Howell Farms	$ 40,951.82	glyphosate	settled in full
	Steve Busch	$ 15,907.25	glyphosate	settled in full
	King Farms	$ 34,370.71	glyphosate	settled in full *grower portion estimated
	Plank Farms	$ 13,990.29	glyphosate	settled in full
2010	Prible Farms	$ 50,000.00	glyphosate	estimated loss, awaiting settlement
		$ 1,142,740.89		

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October 15, 2010

Mr. Phil Miller
Vice President, Global Regulatory
Monsanto Company
800 North Lindbergh Blvd.
St. Louis, MO 63167

Dear Mr. Miller:

In connection with the September 30, 2010 hearing of the Domestic Policy Subcommittee, entitled, "Are "Superweeds" an Outgrowth of USDA Biotech Policy? (Part II)", I hereby request that you provide answers in writing to the following questions for the hearing record.

1. You say in your written testimony that genetically engineered crops increase farmer profits, yields and carbon sequestration. As you know, the scope of the hearing was limited to herbicide-resistant crops. Please provide the Subcommittee with all documents that provide a basis for those three claims as they would relate to herbicide-resistant crops.
2. At what point was glyphosate-resistance in weeds first predicted and when was it first documented by the Company or Company-funded scientists? Please provide all citations for published research.
3. Are voluntary stewardship measures sufficient to prevent and/or mitigate glyphosate resistance in weeds? Please provide specific examples of purely voluntary stewardship practices that have successfully prevented or contained the spread of glyphosate resistance in weeds on a broad basis involving many individual farmers.
4. Given that including in a rotation non-glyphosate-resistant crops can be important to preventing glyphosate resistance in weeds, what varieties of non-glyphosate-resistant corn, cotton and soy does Monsanto and its affiliated seed companies offer to farmers?
5. Concerning the development of other herbicide-resistant resistant crops, including dicamba-resistant soybeans, what is the scale of Monsanto Company's research and development efforts to create other herbicide resistant crops?

6. Is Dicamba-resistance in weeds currently predicted by the Company or any Company-funded scientist in fields that will be growing Dicamba-resistant soybeans?
7. What lessons has the Company taken from glyphosate-resistance in weeds to apply to preventing or mitigating Dicamba resistance in weeds?
8. Does the Company believe that voluntary stewardship measures alone will be sufficient to prevent Dicamba resistance in weeds from occuring after Dicamba-resistant crops are planted?
9. In light of producer concerns for horticultural crops once Dicamba gains more widespread use after Dicamba-resistant crops are deregulated, what measures does the Company believe will prevent producer concerns from being realized?
10. In the hearing, we received testimony expressing concern that Dicamba/Roundup tolerant soybean will cause collateral injury to fruit and vegetable farmers and backyard gardeners. In fact, your testimony acknowledges that concern. In the event that such injury should materialize, who will be liable for the economic costs of the affected farmers? Will it be Monsanto or another party?
11. Concerning USDA regulation of biotech crops: Specifically, does the Company believe USDA has authority under the Plant Protection Act (codified at 7 U.S.C. § 7701 *et. seq.*) and its regulations to regulate GE crops so as to prevent herbicide-resistant weeds? Has the Company ever taken a position on that question? Please provide all documents expressing a legal opinion on that question.

Ranking member Jordan submits the following additional questions:

1. Who is responsible for addressing the issue of herbicide-resistant weeds?

2. The advertorial you received during the September 30, 2010 hearing contained a recommendation for growers to use two modes of action. Can you explain what that means?

The Oversight and Government Reform Committee is the principal oversight committee in the House of Representatives and has broad oversight jurisdiction as set forth in House Rule X.

We request that you provide written answers to these questions as soon as possible, but in no case later than **5:00 p.m. on October 30, 2010**.

If you have any questions regarding this request, please contact Jaron Bourke, Staff Director at (202) 225-6427.

Sincerely,

Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee

cc: Jim Jordan
Ranking Minority Member

MONSANTO

MONSANTO COMPANY
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http://www.monsanto.com

November 12, 2010

The Hon. Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee
House Committee on Oversight and Government Reform

Dear Chairman Kucinich:

On behalf of Monsanto, thank you for the opportunity to respond to questions submitted for the record following your hearing on September 30th. I hope the information provided assists the Subcommittee in its analysis of the issues surrounding biotechnology regulatory policy and the development of herbicide resistant weeds.

This is an important topic for not only our industry but also for our Nation and farmers around the world as we seek to feed an ever-growing global population.

Please do not hesitate to contact me if I can be of further assistance.

Sincerely,

Philip Miller
Vice President, Regulatory
Monsanto Company

Cc: The Hon. Jim Jordan, Ranking Member

QUESTIONS FROM CHAIRMAN KUCINICH

1. **You say in your written testimony that genetically engineered crops increase farmer profits, yields and carbon sequestration. As you know, the scope of the hearing was limited to herbicide-resistant crops. Please provide the Subcommittee with all documents that provide a basis for those three claims as they would relate to herbicide-resistant crops.**

   Provided below is a list of publications that establish that GE crops increase farmer profits, yields and carbon sequestration. Because the benefits of herbicide-tolerant and insect-resistant crops are additive when these traits are combined in the same crop, researchers often assess the cumulative benefits of these traits. The list of publications provided includes analysis of the benefits of herbicide-tolerant and insect-resistant crops separately and combined. In a recent comprehensive analysis, the National Research Council Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability concluded, "In general, the committee finds that genetic-engineering technology has produced substantial net environmental and economic benefits to U.S. farmers compared with non-GE crops in conventional agriculture."

   List of Publications:

   Brookes, G. and P. Barfoot. "Global Impact of Biotech Crops: Environmental Effects, 1996-2008." AgBioForum 13(2010):76-94.

   Brookes, G. and P. Barfoot. "Global Impact of Biotech Crops: Income and Production Effects, 1996-2007," AgBioForum 12(2009):184-208.

   Brookes, G. and P. Barfoot. "Global Impact of Biotech Crops: Socio-Economic & Environmental Effects 1996–2007." Outlooks on Pest Management (2009), 1-7.

   Brookes, G., T.H. Tse, S. Tokgog, and G. Elobeid. "The Production and Price Impact of Biotech Corn, Canola, and Soybean Crops." AgBioForum 13(2010):25.52.

   CTIC. 2010. Facilitating Conservation Farming Practices and Enhancing Environmental Sustainability with Agricultural Biotechnology Executive Summary. http://www.ctic.org/BiotechSustainability.

   CTIC. 2009. Top 10 Benefits of Conservation Tillage. Farm and Food Facts '09. Purdue University Conservation Technology Information Center, West Lafayette, Indiana. http://www.ilfb.org/fff2009/37.pdf.

   Edgerton, M. 2009. Increasing Crop Productivity to Meet Global Needs for Feed, Food, and Fuel. Plant Physiology. 149: 7–13.

   Fawcett, R.,Towry, D. Conservation Tillage and Plant Biotechnology: How New Technologies Can Improve the Environment by Reducing the Need to Plow. Conservatory Technology Information Center, West Lafayette, Indiana. (2002) pp. 1-24.

Fernandez-Cornejo, J. Mishra, A., Nehring, R., Hendricks, C., Southern, M., Gregory, A. Off-farm Income, Technology Adoption, and Farm Economic Performance. USDA-ERS Report No. 36 92007. http://www.ers.usda.gov/Publications/err36/err36_reportsummary.pdf.

NRC Report. "Impact of Genetically Engineered Crops on Farm Sustainability in the United States." Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability; National Research Council. http://www.nap.edu/catalog/12804.html.

Roberts, R.K., B.C. English, Q. Gao, and J.A. Larson. "Simultaneous Adoption of Herbicide-Resistance and Conservation-Tillage Cotton Technologies." Journal of Agricultural and Applied Economics 38(2006):629-643.

Qaim, M. 2009. The Economics of Genetically Modified Crops. Annu. Rev. Resour. Econ. 1:665–693.

2. **At what point was glyphosate-resistance in weeds first predicted and when was it first documented by the Company or Company-funded scientists? Please provide all citations for published research.**

   Weeds and other organisms can adapt to their environments. The development of weed populations resistant to any herbicide is in theory an eventual outcome of its use and is influenced by inherent characteristics of the chemistry and application of agricultural practices. In that sense, from a scientific perspective, the eventual discovery of weed populations resistant to any herbicide including glyphosate can be theoretically anticipated based on the principles of population biology and selection; however it is not possible to anticipate with any specificity or probability when, under what circumstances, in what geographies or in what species resistance will occur.

   The first known and documented case of glyphosate resistance was a population of weeds in Australia discovered in 1996 in conventional (non-biotech) cropping systems (reference www.weedscience.org) after 15 years of successful glyphosate use in those systems. (Attached is the original publication). Monsanto did not "predict" this development. Upon discovery of this population that was potentially resistant, Monsanto collaborated with the public sector scientists who made the discovery. Attached is a Monsanto authored publication using seed from this first glyphosate resistant population, regarding efforts to understand the mechanism of resistance.

   Powles, S. B., D.F. Lorraine-Colwill, J.J. Dellow, and C. Preston. 1998. Evolved resistance to glyphosate in rigid ryegrass (Lolium rigidum) in australis. Weed Science, 46: 604-607.

   Feng, Paul C.C., James E. Pratley and Josephe A Bohn. 1999. Reistance to glyphosate in Lolium rgidum. II. Uptake, translocation and metabolism. Weed Sceince, 47: 412-415.

3. **Are voluntary stewardship measures sufficient to prevent and/or mitigate glyphosate resistance in weeds? Please provide specific examples of purely voluntary stewardship practices that have successfully prevented or contained the spread of glyphosate resistance in weeds on a broad basis involving many individual farmers.**

   To be clear, neither the scientific community nor any other community of experts can identify any

practice or product that will prevent resistance to any herbicide. However, the conscientious implementation of agronomic best management practices (BMPs) can delay or mitigate the development of resistance. Such BMPs can and should be established in market-driven voluntary stewardship programs.

Specific to herbicide tolerant crops, market research, as described in the following reference, indicates that growers are increasingly adopting best management practices to manage weed resistance. These practices are being implemented voluntarily by growers. As an example, in the 2007 market research study approximately 50 % of Roundup Read corn growers use other herbicides in addition to glyphosate. More recent market research indicates that the percentage of RR corn growers using other herbicides has increased significantly in 2010.

Frisvold, G. B., T. M. Hurley, and P.D. Mitchell. 2009. Adoption of Best management Practices to control Weed Resistance by Corn, Cotton, and Soybean Growers. AgBioForun, 12(3&4): 370-381.

4. **Given that including in a rotation non-glyphosate-resistant crops can be important to preventing glyphosate resistance in weeds, what varieties of non-glyphosate-resistant corn, cotton and soy does Monsanto and its affiliated seed companies offer to farmers?**

As previously mentioned, neither the scientific community nor any other community of experts can identify any practice or product that will prevent resistance to any herbicide. However, the conscientious implementation of agronomic best management practices (BMPs) can delay or mitigate the development of resistance. Such BMPs can and should be established in market-driven voluntary stewardship programs.

Best practices for managing weed resistance involve the use of a diversified weed management program that can include the use of multiple herbicide modes of action in mixtures, sequences or in rotation with or without the use of tillage and cultural practices such as crop rotation. Importantly, it is not the trait present in the crop but rather the herbicide(s) used in the system that provides the diversity of weed management practices that are important to minimize the chance of the development of resistant populations. Using herbicide mixtures and sequences even if repeated over multiple years can be more effective than rotating herbicides across years as highlighted in the following research papers. Thus, rotating to non-transgenic or transgenic non-glyphosate-tolerant crops is not critical for implementing a successful, diversified weed management program.

To address your question regarding non-glyphosate tolerant varieties, Monsanto commercially offers 44 non-glyphosate tolerant corn hybrids, seven cotton varieties and seven soybean varieties. Non-glyphosate tolerant hybrids and varieties are also offered by other seed companies.

Beckie, H.J. and Xavier Reboud. 2009. Selecting for Weed Resistance: Herbicide Rotation and Mixture. Weed Technology 23:363-370.

Diggle, A.J., P.B. Neve, and F.P. Smith. 2003. Herbicides used in combination can reduce the probability of herbicide resistance in finite weed populations. Weed Research 43: 371-382.

Maxwell B.D., M.L. Roush and S.R. Radosevich. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. Weed Technology 4, 2-13.

5. **Concerning the development of other herbicide-resistant resistant (sic) crops, including dicamba-resistant soybeans, what is the scale of Monsanto Company's research and development efforts to create other herbicide resistant crops?**

   Monsanto's research and development pipeline includes the following projects: dicamba-glufosinate tolerant cotton, dicamba tolerant soybeans, dicamba-glufosinate tolerant corn, and FOPS tolerant corn.

6. **Is Dicamba-resistance in weeds currently predicted by the Company or any Company funded scientist in fields that will be growing Dicamba-resistant soybeans?**

   Weeds and other organisms can adapt to their environments. The development of weed populations resistant to any herbicide is in theory an eventual outcome of its use and is influenced by inherent characteristics of the chemistry and application of agricultural practices. In that sense, from a scientific perspective, the eventual discovery of weed populations resistant to any herbicide including glyphosate can be theoretically anticipated based on the principles of population biology and selection; however it is not possible to anticipate with any specificity or probability when, under what circumstances, in what geographies or in what species resistance will occur.

   To date there are two species with known resistance to dicamba in the U.S. after over 40 years of use; kochia (Kochia scoparia) and prickly lettuce (Lactuca serriola) (www weedscience.org). The use of dicamba in dicamba tolerant (DT) soybeans is not expected to result in an increase in resistant populations of species known to be dicamba resistant nor to increase the total number of dicamba resistant species. In DT soybeans, dicamba will predominantly be used in combination with other herbicides with different modes of action, principally glyphosate, but also with other soil-active herbicides (Johnson et al. 2010). The presence of multiple herbicides in the weed management system greatly diminishes the chance that weed resistance will occur as noted in the references listed for question 4, above.

   Johnson, B., Young, B., Matthews, J., Marquardt, P., Slack, C., Bradley, K., York, A., Culpepper, S., Hager, A., Al-Khatib, K., Steckel, L., Moechnig, M., Loux, M., Bernards, M., and Smeda, R. 2010. Weed control in dicamba-resistant soybeans. Online. Crop Management doi:10.1094/CM-2010-0920-01-RS.

7. **What lessons has the Company taken from glyphosate-resistance in weeds to apply to preventing or mitigating Dicamba resistance in weeds?**

   Neither the scientific community nor any other community of experts can identify any practice or product that will prevent resistance to any herbicide. However, the conscientious implementation of agronomic best management practices (BMPs) can delay or mitigate the development of resistance. Such BMPs can and should be established in market-driven voluntary stewardship programs.

   We and other scientists have learned that where diversity in weed management systems is maintained, the use of glyphosate (and other herbicides) for weed control can be sustained (Powles, 2008). A diverse weed management program will be implemented for dicamba-tolerant crop systems. As noted above in question 6, use of dicamba in dicamba tolerant (DT) soybeans will predominantly be used in combination with other herbicides with different modes of action,

principally glyphosate, but also with other soil-active herbicides (Johnson et al. 2010). In addition, farmer recommendations will be in place for surveillance and the early identification of dicamba resistance, should it occur, and for ways to manage the occurrence and to limit the spread of potential dicamba-resistant weeds in soybeans and crops rotated with soybeans.

Powles, Stephen B. 2008. Evolution in Action: glyphosate-resistant weeds threaten world crops. Outlooks on Pest Management, December 2008.

8. **Does the Company believe that voluntary stewardship measures alone will be sufficient to prevent Dicamba resistance in weeds from occurring after Dicamba-resistant crops are planted?**

   Yes, however, and again to be clear, neither the scientific community nor any other community of experts can identify any practice or product that will prevent resistance to any herbicide. However, the conscientious implementation of agronomic best management practices (BMPs) can delay or mitigate the development of resistance. Such BMPs can and should be established in market-driven voluntary stewardship programs.

   As noted in the answer to question 3, voluntary stewardship measures have been effective for managing weed resistance in agriculture and will be effective for managing weed resistance in dicamba-tolerant crop systems. As noted above in questions 6-7, in DT soybeans, dicamba will predominantly be used in combination with other herbicides with different modes of action, principally glyphosate, but also with other soil-active herbicides (Johnson et al. 2010). Thus the use of dicamba in dicamba tolerant (DT) soybeans is not expected to result in an increase in resistant populations of species known to be dicamba resistant nor to increase the number of dicamba resistant species. The presence of multiple herbicides in the weed management system greatly diminishes the chance that weed resistance to dicamba will occur.

9. **In light of producer concerns for horticultural crops once Dicamba gains more widespread use after Dicamba-resistant crops are deregulated, what measures does the Company believe will prevent producer concerns from being realized?**

   The potential off-site movement of herbicides is not new or unique to dicamba-tolerant crops. The EPA regulates the use of herbicides, including off-site movement. The EPA-approved label will include provisions designed to minimize drift. Farmers are required to follow herbicide labels and are aware of the importance of following BMPs to minimize off-target movement of herbicides.

   Monsanto is working with multiple stakeholders, including soybean growers as well as growers of crops that may be grown nearby, to design appropriate stewardship measures to address the potential off-site movement of dicamba when used with dicamba-tolerant crops. We are also working with other companies to develop improved dicamba formulations that reduce the potential for off-site movement.

10. **In the hearing, we received testimony expressing concern that Dicamba/Roundup tolerant soybean will cause collateral injury to fruit and vegetable farmers and backyard gardeners. In fact, your testimony acknowledges that concern. In the event that such injury should materialize, who will be liable for the economic costs of the affected farmers? Will it be Monsanto or another party?**

To clarify, it is the application of herbicides (regulated by the EPA), not the soybeans, that has raised the concern regarding potential off-site movement and injury to neighboring crops. The soybeans have no characteristics that would result in injury of any kind, including to farmers or gardeners. Liability for economic costs of persons affected by offsite movement from the application of pesticides depends on the facts of the situation and the applicable state law. To the extent offsite movement results from the use of a pesticide in a manner that is not in accordance with the product's EPA-approved label, such use would be a violation of federal law. EPA's registration of a pesticide is a determination that when used in accordance with label directions, the pesticide will cause no unreasonable adverse effects on the environment, a concept comparable to the analysis under NEPA.

11. **Concerning USDA regulation of biotech crops: Specifically, does the Company believe USDA has authority under the Plant Protection Act (codified at 7 U.S.C. 7701 et. seq.) and its regulations to regulate GE crops so as to prevent herbicide-resistant weeds? Has the Company ever taken a position on that question? Please provide all documents expressing a legal opinion on that question.**

No.

As Dr. Miller provided in his written statement, weed resistance is an herbicide issue, not a biotech crop issue, and is dependent on how herbicides are used. Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Federal Government's Coordinated Framework for regulating biotechnology-derived products, EPA is the agency charged with analyzing the potential environmental impacts from the use of herbicides and other pesticides. The EPA's determinations are the functional equivalent of a NEPA analysis.

In complying with the National Environmental Policy Act (NEPA), USDA evaluates potential impacts to the human environment related to its decision to deregulate a biotech crop. The use of herbicides in conjunction with an herbicide-tolerant crop, and any associated impact on the potential development of weed resistance, is considered by USDA as part of its NEPA evaluation. USDA does not, however, have the authority to regulate herbicides or weed resistance to herbicides under the Plant Protection Act, which regulates plant pests and noxious weeds.

The Company's position on this question is aligned with the industry as expressed by BIO (the Biotechnology Industry Organization) and CLA (CropLife America). The opinion of Monsanto in-house counsel is reflected in these responses.

QUESTIONS FROM RANKING MEMBER JORDAN

1. **Who is responsible for addressing the issue of herbicide-resistant weeds?**

There is not just one reason why resistance develops, nor is there just one way to best manage it. Monsanto has a shared responsibility with farmers, university researchers, extension scientists and others in industry to provide the best possible advice, options and recommendations for how to

proactively and reactively manage resistance. The U.S. EPA regulates use of herbicides and its regulatory position on resistance is set forth in PR Notice 2001-5. Industry, the public sector and farmers also have the responsibility to monitor for resistance and to provide early identification of herbicide resistant weeds for farmers. The farmer and/or land owner ultimately decides what weed management practices are best and most appropriate for use on his crops. Green and Owen, 2010, provide an overview of key concepts and management programs that need to be considered in herbicide resistant crops to ensure sustainability of the herbicides used in these crops.

Green, J.M. and M.D.K. Owen. 2010. Herbicide-resistant crops: utilities and limitation for herbicide-resistant weed management. Online: J. Agric. Food Chem. Doi:10.102/jf101286h.

2. **The advertorial you received during the September 30, 2010 hearing contained a recommendation for growers to use two modes of action. Can you explain what that means?**

Each herbicide is defined in large part by its mode of action for controlling weeds. This provides information about what plant mechanisms are disrupted when the herbicide is sprayed on a weed. The mechanism of weed resistance and the associated naturally occurring genes that can confer resistance to a herbicide is often related to the mode of action of the herbicide. Estimates of the frequency of resistance genes within weed populations differ by herbicide but are typically very low for weed populations that remain susceptible to the herbicides. When two herbicides, with different modes of action, both effective for controlling a weed are used in combination, the likelihood that herbicide resistant genes for both herbicides occur together in the same plant is very low. From a management standpoint, the use of mixtures of two or more herbicides with different modes of action is predicted by model simulations to delay resistance much longer than the use of either herbicide alone or by rotating herbicides in successive crops. The principle of using multiple modes of action is also a basic component of resistance management of insects and fungi to insecticides and fungicides. The following references may be reviewed relative to this discussion.

Gressel, J. and L. A. Segel 1990. Modeling the effectiveness of herbicide rotations and mixtures as strategies to delay or preclude resistance Weed Technology 4: 186-198.

Wrubel, R.P. and J. Grssel. 1994. Are herbicide mixtures useful for delaying the rapid evolution of resistance – a case study. Weed Technology 8, 635-648.

Beckie, H. J. 2006. Herbicide-resistant weeds: Management tactics and practices. Weed Technology 20(3): 793-814.

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Global Impact of Biotech Crops: Environmental Effects, 1996-2008

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This article updates the assessment of the impact commercialized agricultural biotechnology is having on global agriculture from an environmental perspective. It focuses on the impact of changes in pesticide use and greenhouse gas emissions arising from the use of biotech crops. The technology has reduced pesticide spraying by 352 million kg (-8.4%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops (as measured by the indicator the environmental impact quotient) by 16.3%. The technology has also significantly reduced the release of greenhouse gas emissions from this cropping area, which, in 2008, was equivalent to removing 6.9 million cars from the roads.

Key words: pesticide, active ingredient, environmental impact quotient, carbon sequestration, biotech crops, no tillage.

Introduction

This study presents the findings of research into the global environmental impact of biotech crops since their commercial introduction in 1996. It updates the findings of earlier analyses presented by the authors in *AgBioForum* 8(2&3), 9(3), and 11(1).[1]

The environmental impact analysis undertaken focuses on the impacts associated with changes in the amount of insecticides and herbicides applied to the biotech crops relative to conventionally grown alternatives. The analysis also examines the contribution of biotech crops towards reducing global greenhouse gas (GHG) emissions.

The analysis is mostly based on that of existing farm-level impact data from biotech crops. Primary data for impacts of commercial biotech cultivation on both pesticide usage and greenhouse gas emissions is, however, limited and is not available for every crop, in every year and for each country. Nevertheless, all identified, representative, previous research has been utilized. This has been used as the basis for the analysis presented, although, where relevant, primary analysis has been undertaken from base data.

Environmental Impacts from Insecticide and Herbicide Use Changes

Methodology

Assessment of the impact of biotech crops on insecticide and herbicide use requires comparisons of the respective weed- and pest-control measures used on biotech versus the 'conventional alternative' form of production. This presents a number of challenges relating to availability and representativeness. Comparison data ideally derives from farm-level surveys, which collect usage data on the different forms of production. A search of literature on biotech crop impact on insecticide or herbicide use at the trait, local, regional, or national level shows that the number of studies exploring these issues is limited (e.g., Pray, Huang, Hu, & Rozelle, 2002; Qaim & De Janvry, 2005; Qaim & Traxler, 2002) with even fewer (e.g., Brookes, 2003, 2005), providing data to the pesticide (active ingredient) level. Second, national-level pesticide usage survey data is also extremely limited; in fact, there are no published annual pesticide usage surveys conducted by national authorities in any of the countries currently growing biotech traits, and the only country in which pesticide usage data is collected (by private market-research companies) on an annual basis and which allows a comparison between biotech and conventional crops to be made is the United States.[2]

1. *Readers should note that some data presented in this article are not directly comparable with data presented in previous articles because the current article takes into account the availability of new data and analysis (including revisions to data for earlier years).*

2. *The US Department of Agriculture also conducts pesticide-usage surveys, but these are not conducted on an annual basis (e.g., the last time corn was included was 2005) and do not disaggregate usage by production type (biotech versus conventional).*

Unfortunately, even where national survey data is available on usage, the data on conventional crop usage may fail to be reasonably representative of what herbicides and insecticides might be expected to be used in the absence of biotechnology. When biotech traits dominate total production (e.g., for soybeans, corn, cotton, and canola in the United States since the early 2000s), the conventional cropping dataset used to identify pesticide use relates to a relatively small share of total crop area and therefore is likely to underestimate what usage would probably be in the absence of biotechnology. The reasons why this conventional cropping dataset is unrepresentative of the levels of pesticide use that might reasonably be expected to be used in the absence of biotechnology include the following.

- While the levels of pest and weed problems/damage vary by year, region, and within region, farmers who continue to farm conventionally are often those with relatively low levels of pest or weed problems, and hence see little, if any, economic benefit from using the biotech traits targeted at these agronomic problems. Their pesticide usage levels therefore tend to be below the levels that would reasonably be expected to be used to control these weeds and pests on an average farm. A good example to illustrate this relates to the US cotton crop where, for example, in 2008, nearly half of the conventional cotton crop was located in Texas. Here, levels of bollworm pests (the main target of biotech insect-resistant cotton) tend to be consistently low, and cotton farming systems are traditionally of an extensive, low input nature (e.g., the average cotton yield in Texas was about 82% of the US average in 2008).
- Some of the farms continuing to use conventional (non-biotech) seed traditionally use extensive, low-intensity production methods (including organic) in which limited (below average) use of pesticides is a feature (see, for example, the Texas cotton example above). The usage pattern of this subset of growers is therefore likely to understate usage for the majority of farmers if all crops were conventional.
- Many of the farmers using biotech traits have experienced improvements in pest and weed control from using this technology relative to the conventional control methods previously used. If these farmers were to now switch back to using conventional techniques—based wholly on pesticides—it is likely that most would wish to maintain the levels of pest/weed control delivered with use of the biotech traits and therefore would use higher levels of pesticide than they did in the pre-biotech crop days.

To overcome these problems in the analysis of pesticide use changes arising from the adoption of biotech crops (i.e., where biotech traits account for the majority of total plantings), presented in this article,[3] actual recorded usage levels for the biotech crops are used (based on survey data), with the conventional alternative (counterfactual situation) identified based on opinion from extension advisors and industry specialists as to what farmers might reasonably be expected to use in terms of crop protection practices and usage levels of pesticide.[4] This methodology has been used by others, for example Johnson and Strom (2007). Details of how this methodology has been applied to the 2008 calculations, sources used for each trait/country combination examined and examples of typical conventional versus biotech pesticide applications are provided in Appendices A and B.

The most common way in which changes in pesticide use with biotech crops has been presented in the literature has been in terms of the volume (quantity) of pesticide applied. While comparisons of total pesticide volume used in biotech and conventional crop production systems are a useful indicator of associated environmental impacts, amount of active ingredient used is an imperfect measure because it does not account for differences in the specific pest-control programs used in biotech and conventional cropping systems. For example, different specific products used in biotech versus conventional crop systems, differences in the rate of pesticides used for efficacy, and differences in the environmental characteristics (mobility, persistence, etc.) are masked in general comparisons of total pesticide volumes used.

In this article, the pesticide-related environmental impact changes associated with biotech crop adoption

3. *Also see earlier work by the authors (Brookes & Barfoot, 2006, 2007, 2008, 2009b).*
4. *In other words, Brookes and Barfoot draw on the findings of work by various researchers at the National Center for Food and Agriculture Policy (Carpenter & Gianessi, 1999; Johnson & Strom, 2007; Sankula & Blumenthal, 2003, 2006; also see http://www.ncfap.org). This work consults with in excess of 50 extension advisors in almost all of the states growing corn, cotton, and soybeans and therefore provides a reasonably representative perspective on likely usage patterns.*

Table 1. Impact of changes in the use of herbicides and insecticides from growing biotech crops globally 1996-2008.

Trait	Change in volume of active ingredient used (million kg)	Change in field EIQ impact (in terms of million field EIQ/ha units)	% change in ai use on biotech crops	% change in environmental impact associated with herbicide & insecticide use on biotech crops	Area biotech trait 2008 (million ha)
GM HT soybeans	-50.45	-5,314.8	-3.0	-16.6	62.47
GM HT maize	-111.58	-2,724.2	-7.5	-8.5	22.40
GM HT canola	-13.74	-437.2	-17.6	-24.3	5.83
GM HT cotton	-6.29	-188.4	-3.4	-5.5	2.41
GM IR maize	-29.89	-1,007.0	-35.3	-29.4	36.04
GM IR cotton	-140.6	-6,555.7	-21.9	-24.8	13.20
GM HT sugar beet	+0.13	-0.46	+10	-2	0.26
Totals	**-352.42**	**-16,227.76**	**-8.4**	**-16.3**	**142.61**

are examined in terms of changes in the volume (amount) of active ingredient applied but supplemented by the use of an alternative indicator, developed at Cornell University in the 1990s: the environmental impact quotient (EIQ). The EIQ indicator, developed by Kovach, Petzoldt, and Degni, and Tette (1992) and updated annually, effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare.' The EIQ value is multiplied by the amount of pesticide active ingredient (ai) used per hectare to produce a field EIQ value. For example, the EIQ rating for glyphosate is 15.33. By using this rating multiplied by the amount of glyphosate used per hectare (e.g., a hypothetical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.86/ha.

The EIQ indicator used is therefore a comparison of the field EIQ/ha for conventional versus biotech crop production systems, with the total environmental impact or load of each system, a direct function of respective field EIQ/ha values and the area planted to each type of production (biotech versus conventional). The use of environmental indicators is commonly used by researchers, and the EIQ indicator has been, for example, cited by Brimner, Gallivan, and Stephenson (2004)—in a study comparing the environmental impacts of biotech and conventional canola—and by Kleiter et al. (2005).

The EIQ indicator provides an improved assessment of the impact of biotech crops on the environment when compared to only examining changes in volume of active ingredient applied, because it draws on some of the key toxicity and environmental exposure data related to individual products, as applicable to impacts on farm workers, consumers, and ecology. Readers should, however, note that the EIQ is an indicator only and does not take into account all environmental issues and impacts. It is therefore not a comprehensive indicator. Detailed examples of the relevant amounts of active ingredient used and their associated field EIQ values for biotech versus conventional crops for the year 2008 are presented in Appendix B.

Results

Biotech traits have contributed to a significant reduction in the environmental impact associated with insecticide and herbicide use on the areas devoted to biotech crops (Table 1). Since 1996, the use of pesticides on the biotech crop area was reduced by 352 million kg of active ingredient (8.4% reduction), and the environmental impact associated with herbicide and insecticide use on these crops—as measured by the EIQ indicator—fell by 16.3%. In absolute terms, the largest environmental gain has been associated with the adoption of GM IR cotton and reflects the significant reduction in insecticide use that the technology has allowed, in what has traditionally been an intensive user of insecticides. The volume of herbicides used in biotech soybean crops also decreased by 50 million kg (1996-2008), a 3% reduction, while the overall environmental impact associated with herbicide use on these crops decreased by a significantly larger 16.6%. This highlights the switch in herbicides used with most GM HT crops to active ingredients with a more environmentally benign profile than the ones generally used on conventional crops.

Important environmental gains have also arisen in the maize and canola sectors. In the maize sector, herbicide and insecticide use decreased by 141.5 million kg and the associated environmental impact of pesticide use on this crop area decreased due to a combination of reduced insecticide use (29.4%) and a switch to more environmentally benign herbicides (8.5%). In the canola sector, farmers reduced herbicide use by 13.7 million kg (a 17.6% reduction) and the associated environmental

Table 2. Biotech crop environmental benefits from lower insecticide and herbicide use 1996-2008: Developing versus developed countries.

	Change in field EIQ impact (in terms of million field EIQ/ha units): Developed countries	Change in field EIQ impact (in terms of million field EIQ/ha units): Developing countries
GM HT soybeans	3,692.8	1,622.0
GM HT maize	2,674.9	49.3
GM HT cotton	153.5	34.9
GM HT canola	437.2	0
GM IR corn	983.8	23.2
GM IR cotton	443.3	6,112.4
GM HT sugar beet	0.46	0
Total	**8,385.96**	**7,841.8**

impact of herbicide use on this crop area fell by 24.3% due to a switch to more environmentally benign herbicides.

In terms of the division of the environmental benefits associated with less insecticide and herbicide use for farmers in developing countries relative to farmers in developed countries, Table 2 shows roughly a 50% split of the environmental benefits (1996-2008) in developed and developing countries. Three quarters of the environmental gains in developing countries have been from the use of GM IR cotton.

Impact on Greenhouse Gas Emissions

Methodology

The methodology used to assess impact on greenhouse gas emissions combines reviews of literature relating to changes in fuel and tillage systems and carbon emissions coupled with evidence from the development of relevant biotech crops and their impact on both fuel use and tillage systems. Reductions in the level of GHG emissions associated with the adoption of biotech crops is acknowledged in a wide body of literature (CTIC, 2002; Fabrizzi, Morónc, & García, 2003; Jasa, 2002; Johnson et al., 2005; Lazarus & Selley, 2005; Liebig et al., 2005; Reicosky, 1995; Robertson, Paul, & Harwood, 2000; West & Post, 2002). First, biotech crops contribute to a reduction in fuel use due to less frequent herbicide or insecticide applications and a reduction in the energy use in soil cultivation. For example, Lazarus and Selley (2005) estimated that one pesticide spray application uses 1.045 liters of fuel, which is equivalent to 2.87 kg/ha of carbon dioxide emissions. In this analysis, we used the conservative assumption that only GM IR crops reduced spray applications with the number of spray applications of herbicides remaining the same for conventional production systems.[5]

In addition, there has been a shift from conventional tillage to reduced/no till. This has had a marked impact on tractor fuel consumption due to energy-intensive cultivation methods being replaced with no/reduced tillage and herbicide-based weed control systems. The GM HT crop where this is most evident is GM HT soybeans. Here, adoption of the technology has made an important contribution to facilitating the adoption of reduced or no-tillage farming.[6] Before the introduction of GM HT soybean cultivars, no-tillage (NT) systems were practiced by some farmers using a number of herbicides and with varying degrees of success. The opportunity for growers to control weeds with a non-residual foliar herbicide as a "burndown" pre-seeding treatment followed by a post-emergent treatment when the soybean crop became established has made the NT systems more reliable, technically viable, and commercially attractive. These technical advantages combined with the cost advantages have contributed to the rapid adoption of GM HT cultivars and the near doubling of the NT soybean area in the United States (also more than a five-fold increase in Argentina). In both countries, GM HT soybeans are estimated to account for more than 95% of the NT soybean crop area in 2007/8.

Substantial growth in NT production systems have also occurred in Canada, where the NT canola area increased from 0.8 million ha to 2.6 million ha (equal to about half of the total canola area) between 1996 and 2005 (95% of the NT canola area is planted with GM HT cultivars). Similarly the area planted to NT in the US cotton crop increased from 0.2 million ha to 1 million ha over the same period (of which 86% is planted to GM HT cultivars) and has remained at this share of the total crop in 2007 and 2008.

The fuel savings resulting from changes in tillage systems used in this article are drawn from estimates from studies by Jasa (2002), CTIC (2002), and the University of Illinois (2006). The adoption of NT farming systems is estimated to reduce cultivation fuel usage by 32.3 liters/ha compared with traditional conventional

5. *Evidence from different countries varies, with some countries exhibiting on average no change and others showing a small net reduction in the number of spray runs.*
6. *See, for example, CTIC (2002) and American Soybean Association (2001).*

tillage (CT; which has an average usage of 43.7 liters/ha) and by 19.33 liters/ha compared with (the average of) reduced tillage (RT) cultivation methods (which has an average usage of 30.72 liters/ha). In turn, this results in reductions of carbon dioxide emissions of 88.81 kg/ha for NT relative to CT and 35.66 kg/ha for RT relative to CT.[7]

Secondly, the use of 'no-till' and 'reduced-till' farming systems that utilize less ploughing increase the amount of organic carbon in the form of crop residue that is stored or sequestered in the soil. This carbon sequestration reduces carbon dioxide emissions into the environment. Rates of carbon sequestration have been calculated for cropping systems using normal tillage and reduced tillage and these were incorporated in the analysis on how GM crop adoption has played an important facilitating role in increasing carbon sequestration, and ultimately, on reducing the release of carbon dioxide into the atmosphere. Of course, the amount of carbon sequestered varies by soil type, cropping system, and eco-region. In North America, the Intergovernmental Panel on Climate Change (IPCC, 2006) estimates that the conversion from conventional-tillage to no-tillage systems stores between 50 kg carbon/ha^{-1} yr and 1,300 kg carbon/ha^{-1} yr (average 300 kg carbon/ha^{-1} yr). In the analysis presented below, a conservative saving of 300 kg carbon/ha^{-1} yr was applied to all NT agriculture and 100 kg carbon/ha^{-1} yr was applied to RT agriculture. Where some countries aggregate their no- and reduced-till data (e.g., Argentina), the reduced-tillage saving value of 100 kg carbon/ha^{-1} yr was used. One kg of carbon sequestered is equivalent to 3.67 kg of carbon dioxide. These assumptions were applied to the reduced pesticide spray applications data on GM IR crops, derived from separate analysis and reviews of farm income literature impacts by the authors (see Brookes & Barfoot, 2009a) and the GM HT crop areas using no/reduced tillage (limited to the GM HT soybean crops in North and South America and GM HT canola crop in Canada).[8]

Results

Herbicide-tolerant Soybeans

The United States: Over the 1996-2008 period, the area of soybeans cultivated in the United States increased rapidly from 25.98 million ha to 30.21 million ha. Over the same period, the area planted using conventional tillage is estimated to have fallen by 21.3% (from 7.5 million ha to 5.9 million ha), while the area planted using NT has increased by 62.3% (from 7.7 million ha to 12.5 million ha).

The most rapid rate of adoption of the GM HT technology has been by growers using NT systems (GM HT cultivars accounting for an estimated 99% of total NT soybeans in 2008). This compares with conventional-tillage systems for soybeans, where GM HT cultivars account for about 79% of total conventional-tillage soybean plantings. The importance of GM HT soybeans in the adoption of a NT system has also been confirmed by an American Soybean Association study (ASA, 2001) of conservation tillage. This study found that the availability of GM HT soybeans has facilitated and encouraged farmers to implement reduced-tillage practices; a majority of growers surveyed indicated that GM HT soybean technology had been the factor of *greatest* influence in their adoption of RT practices.

Based on the soybean crop area planted by tillage system, type of seed planted (GM and conventional) and applying the fuel usage consumption rates referred to in the methodology section,[9] the total consumption of tractor fuel has increased by only 2.1% (15.9 million liters)—from 746.4 to 762.4 million liters (1996 to 2008)—while the area planted increased by 16.3%, some 4.3 million ha. Over the same period, the average fuel usage fell 12.2%—from 28.7 liters/ha to 25.2 liters/ha. A comparison of biotech versus conventional pro-

7. *Based on one-liter fuel results in a carbon dioxide saving of 2.75 kg/ha from Lazarus and Selly (2005).*

8. *Due to the likely small-scale impact and/or lack of tillage-specific data relating to GM HT maize and cotton crops (and the US GM HT canola crop), analysis of possible GHG emission reductions in these crops have not been included. The no/reduced-tillage areas to which these soil carbon reductions were applied were limited to the increase in the area planted to no/reduced tillage in each country since GM HT technology has been commercially available. In this way, the authors have tried to avoid attributing no/reduced-tillage soil carbon sequestration gains to GM HT technology on cropping areas that were using no/reduced-tillage cultivation techniques before GM HT technology became available. Also, the development of the no-tillage soybean crops have not been attributed to the plantings of GM HT crops in Brazil due to the rapid development of this production system before GM HT soybean technology was permitted in 2003.*

9. *Our estimates are based on the following average fuel consumption rates: NT 11.4 liter/ha, RT 30.73 liters/ha (the average of fuel consumption for chisel ploughing and disking) and conventional tillage 43.7 liters/ha.*

Table 3. US soybeans: Permanent reduction in tractor fuel consumption and CO_2 emissions 1996-2008.

	Annual reduction based on 1996 average (liters/ha)	Crop area (million ha)	Total fuel saving (million liters)	Carbon dioxide (million kg)
1996	0.0	26.0	0.0	0.00
1997	0.5	28.3	13.7	37.71
1998	1.0	29.1	28.2	77.60
1999	1.0	29.8	30.8	84.73
2000	1.1	30.1	33.1	90.95
2001	1.4	30.0	41.7	114.63
2002	1.7	29.5	49.7	136.70
2003	2.3	29.7	67.5	185.52
2004	2.9	30.3	86.6	238.05
2005	4.2	28.9	120.4	331.18
2006	5.5	30.6	167.5	460.67
2007	3.5	25.8	90.0	247.40
2008	3.5	30.2	105.5	290.20
Total			**834.7**	**2,295.3**

Assumption: Baseline fuel usage is the 1996 level of 28.7 liters/ha.

Table 4. US soybeans: Potential soil carbon sequestration (1996 to 2008).

	Total carbon sequestered (million kg)	Average (kg carbon/ha)
1996	2,640.96	101.7
1997	3,061.99	108.1
1998	3,337.46	114.5
1999	3,431.70	115.0
2000	3,482.75	115.5
2001	3,569.75	119.0
2002	3,619.85	122.5
2003	3,855.54	129.8
2004	4,148.86	137.0
2005	4,432.87	153.5
2006	5,194.42	170.0
2007	3,707.41	144.0
2008	4,348.85	144.0

duction systems shows that in 2008, the average tillage fuel consumption on the biotech planted area was 24.3 liters/ha compared to 36.5 liters/ha for the conventional crop (primarily because of differences in the share of NT plantings).

The cumulative permanent reduction in tillage fuel use in US soybeans is summarized in Table 3. This amounted to a reduction in tillage fuel usage of 834.7 million liters, which equates to a reduction in carbon dioxide emission of 2,295.3 million kg.

Based on the crop area planted by tillage system and type of seed planted (biotech and conventional) and using estimates of the soil carbon sequestered by tillage system for corn and soybeans in continuous rotation (the NT system is assumed to store 300 kg of carbon/ha/year, the RT system assumed to *store* 100 kg carbon/ha/year, and the CT system assumed to *release* 100 kg carbon/ha/year),[10] our estimates of total soil carbon sequestered are (Table 4):

- an increase of 1,707.9 million kg carbon/year (from 2,641 million kg in 1996 to 4,349 million kg carbon/year in 2008 due to increases in both crop area planted and the NT soybean area);
- the average level of carbon sequestered per ha increased by 42.3 kg carbon/ha/year (from 101.7 to 144 kg carbon/ha/year).

Cumulatively, since 1996 the increase in soil carbon due to the increase in NT and RT in US soybean production systems has been 10,370 million kg of carbon which, in terms of carbon dioxide emission equates to a saving of 38,057 million kg of carbon dioxide that would otherwise have been released into the atmosphere (Table 5). This estimate does not, however, take into consideration the potential loss in carbon sequestration that arises when some farmers return to conventional

10. The actual rate of soil carbon sequestered by tillage system is, however dependent upon soil type, soil organic content, quantity, and type of crop residue, so these estimates are indicative averages.

Table 5. US soybeans: Potential additional soil carbon sequestration attributable to NT/RT systems (1996 to 2008).

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered (million kg)	Carbon dioxide (million kg)
1996	0.0	26.0	0.00	0.00
1997	6.4	28.3	181.93	667.69
1998	12.8	29.1	374.36	1,373.89
1999	13.4	29.8	398.45	1,462.32
2000	13.9	30.1	417.99	1,534.01
2001	17.4	30.0	521.04	1,912.23
2002	20.9	29.5	616.89	2,264.00
2003	28.1	29.7	835.71	3,067.05
2004	35.4	30.3	1,071.19	3,931.26
2005	51.8	28.9	1,497.10	5,494.36
2006	68.3	30.6	2,087.44	7,660.89
2007	42.3	25.8	1,089.62	3,998.89
2008	42.3	30.2	1,278.14	4,690.77
Total			**10,369.86**	**38,057.37**

Assumption: Carbon sequestration remains at the 1996 level of 101.7 kg carbon/ha/year.

Table 6. Argentine soybeans: Permanent reduction in tractor fuel consumption and reduction in CO_2 emissions.

	Annual reduction based on 1996 average of 35.8 (l/ha)	Crop area (million ha)	Total fuel saving million liters	Carbon dioxide (million kg)
1996	0.0	5.9	0.0	0.00
1997	1.1	6.4	7.2	19.90
1998	3.4	7.0	23.6	64.93
1999	7.9	8.2	64.8	178.21
2000	10.2	10.6	107.8	296.59
2001	10.2	11.5	117.1	322.12
2002	11.3	13.0	146.7	403.50
2003	11.3	13.5	152.8	420.16
2004	11.3	14.3	162.3	446.46
2005	12.4	15.2	189.2	520.38
2006	13.4	16.2	215.7	593.11
2007	13.4	16.6	221.5	609.10
2008	13.4	17.0	227.0	624.33
Total			**1,635.7**	**4,498.79**

Note: Based on 21.07 liters/ha for NT and RT and 43.7 liters/ha for CT.

tillage and therefore should be treated as a maximum potential rather than an achieved level.

Argentina: Since 1996, the area planted to soybeans in Argentina has increased by 188% (from 5.9 to 17 million ha). Over the same period, the area planted using NT and RT practices also increased by an estimated 672%, from 2.07 to 15.98 million ha, while the area planted using CT decreased 73%, from 3.8 to 1.02 million ha.

As in the United States, a key driver for the growth in NT soybean production has been the availability of GM HT soybean cultivars, which, in 2008, accounted for 97.8% of the total Argentine soybean area.

Between 1996 and 2008 total fuel consumption associated with soybean cultivation increased by an estimated 169.6 million liters (80.2%), from 211.6 to 381.2 million liters/year. However, during this period the average quantity of fuel used per ha fell 37.34% from 35.8 to 22.4 liters/ha, due predominantly to the widespread use of GM HT soybean cultivars and NT/RT systems. If the

Table 7. Argentine soybeans: Potential additional soil carbon sequestration (1996 to 2008).

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered (million kg)	Carbon dioxide (million kg)
1996	0.0	5.9	0.0	0.00
1997	-0.9	6.4	-5.9	-21.57
1998	12.8	7.0	89.1	327.00
1999	52.8	8.2	432.0	1,585.47
2000	72.8	10.6	771.0	2,829.42
2001	72.8	11.5	837.3	3,073.07
2002	82.8	13.0	1,073.6	3,940.24
2003	82.8	13.5	1,118.0	4,102.96
2004	82.8	14.3	1,187.9	4,359.75
2005	92.8	15.2	1,410.8	5,177.47
2006	100.8	16.2	1,628.1	5,975.23
2007	100.8	16.6	1,672.0	6,136.31
2008	100.8	17.0	1,713.8	6,289.71
Total			**11,927.7**	**43,775.07**

Assumption: NT = +150 kg carbon/ha/yr; CT = -100 kg carbon/ha/yr.

proportion of NT/RT soybeans in 2008 (applicable to the total 2008 area planted) had remained at the 1996 level, an additional 1,635.9 million liters of fuel would have been used. At this level of fuel usage, an additional 4,498.79 million kg of carbon dioxide would have otherwise been released into the atmosphere (Table 6).

Applying a conservative estimate of soil carbon retention of 150 kg/carbon/ha/yr for NT/RT soybean cropping in Argentina (tillage data in Argentina does not differentiate between NT and RT), a cumulative total of 11,927.8 million kg of carbon—which equates to a saving of 43,775.1 million kg of carbon dioxide—has been retained in the soil that would otherwise have been released into the atmosphere (Table 7).

Paraguay and Uruguay: NT/RT systems have also become important in soybean production in both Paraguay and Uruguay, where the majority of production in both countries are reported by industry sources to use NT/RT systems.

Using the findings and assumptions applied to Argentina (see above), the savings in fuel consumption for soybean production between 1996 and 2008 (associated with changes in NT/RT systems, the adoption of GM HT technology and comparing the proportion of NT/RT soybeans in 2008 relative to the 1996 level) has possibly amounted to 195.9 million liters. At this level of fuel saving, the reduction in the level of carbon dioxide released into the atmosphere has probably been 538.7 million kg. Applying the same rate of soil carbon retention for NT/RT soybeans as Argentina, the cumulative increase in soil carbon since 1996—due to the increase in NT/RT in Paraguay and Uruguay soybean production systems—has been 2,163.2 million kg of carbon. In terms of carbon dioxide emission, this equates to a saving of 7,938.94 million kg of carbon dioxide that may otherwise have been released into the atmosphere.

Herbicide-tolerant Canola

The analysis presented below relates to Canada only and does not include the US GM HT canola crop. This reflects the lack of information about the level of NT/RT in the US canola crop. Also, the area devoted to GM HT canola in the United States is relatively small by comparison to the corresponding area in Canada (0.39 million ha in the United States in 2008 compared to 5.4 million ha in Canada).

Since 1996 the cumulative permanent reduction in tillage fuel use in Canadian canola is estimated at 347.5 million liters, which equates to reduction in carbon dioxide emission of 955.39 million kg (Table 8).

In terms of the increase in soil carbon associated with the increase in NT and RT in Canadian canola production, the estimated values are summarized in Table 9. The cumulative increase in soil carbon equals 3,227 million kg of carbon, which in terms of carbon dioxide emission equates to a saving of 11,842 million kg of carbon dioxide that would otherwise have been released into the atmosphere.

Table 8. Canadian canola: Permanent reduction in tractor fuel consumption and CO_2 emissions 1996-2008.

	Annual reduction based on 1996 average 35.6 (l/ha)	Crop area (million ha)	Total fuel saving (million liters)	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	1.6	4.9	7.9	21.63
1998	1.6	5.4	8.8	24.11
1999	1.6	5.6	9.0	24.71
2000	1.6	4.9	7.8	21.58
2001	3.2	3.8	12.2	33.62
2002	4.8	3.3	15.8	43.46
2003	6.5	4.7	30.3	83.30
2004	8.1	4.9	39.9	109.68
2005	8.1	5.5	44.3	121.93
2006	9.7	5.2	50.8	139.59
2007	9.7	5.9	57.3	157.51
2008	10.3	6.5	63.4	174.27
Total			**347.5**	**955.39**

Note: Fuel usage NT = 11.4 liters/ha; CT = 43.7 liters/ha.

Table 9. Canada canola: Potential additional soil carbon sequestration (1996 to 2008).

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered (million kg)	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	15.0	4.9	73.1	268.09
1998	15.0	5.4	81.4	298.86
1999	15.0	5.6	83.5	306.31
2000	15.0	4.9	72.9	267.50
2001	30.0	3.8	113.6	416.75
2002	45.0	3.3	146.8	538.67
2003	60.0	4.7	281.4	1,032.56
2004	75.0	4.9	370.4	1,359.46
2005	75.0	5.5	411.8	1,511.40
2006	90.0	5.2	471.4	1,730.21
2007	90.0	5.9	532.0	1,952.39
2008	95.9	6.5	588.6	2,160.16
Total			**3,226.9**	**11,842.36**

Note: NT/RT = +200 kg carbon/ha/yr; CT = -100 kg carbon/ha/yr.

Herbicide-tolerant Cotton and Maize

The contribution to reduced levels of carbon release arising from the adoption of GM HT maize and cotton is likely to have been marginal, and hence no assessments are presented. This conclusion is based on the following.

- Although the area of NT/RT cotton has increased significantly in countries such as the United States, it still only represented an estimated 21%[11] of the total cotton crop in 2007.
- As the soybean-maize rotation system is commonplace in the United States, the benefits of switching to a NT system have largely been examined above for soybeans.
- No significant changes to the average number of spray runs under a GM HT production system rel-

11. *Source: Conservation Technology Information Center, National Crop Residue, Management Survey (2007a, 2007b).*

Table 10. Permanent reduction in global tractor fuel consumption and CO_2 emissions resulting from the cultivation of GM IR cotton 1996-2008.

	Total cotton area in GM IR growing countries excluding India and China (million ha)	GM IR area (million ha) excluding India and China	Total spray runs saved (million ha)	Fuel saving (million liters)	CO2 emissions saved (million kg)
1996	7.49	0.86	3.45	3.60	9.91
1997	7.09	0.92	3.67	3.84	10.56
1998	7.24	1.05	4.20	4.39	12.08
1999	7.46	2.11	8.44	8.82	24.25
2000	7.34	2.43	9.72	10.16	27.94
2001	7.29	2.55	10.19	10.65	29.28
2002	6.36	2.18	8.71	9.10	25.04
2003	5.34	2.19	8.74	9.14	25.13
2004	6.03	2.80	11.20	11.70	32.18
2005	6.34	3.22	12.88	13.46	37.02
2006	7.90	3.94	15.75	16.46	45.27
2007	6.07	3.25	13.00	13.59	37.37
2008	4.99	2.41	9.65	10.08	27.72
Total			**119.60**	**124.99**	**343.75**

Note: Assumptions: 4 tractor passes per ha; 1.045 liters/ha of fuel per insecticide application.

ative to a conventional production system have been reported.

Insect-resistant Cotton

The cultivation of GM IR cotton has resulted in a significant reduction in the number of insecticide spray applications (e.g., Gianessi & Carpenter, 1999). During the period 1996 to 2008, the global cotton area planted with GM IR cultivars (excluding China and India)[12] has increased from 0.86 million ha to 3.94 million ha in 2006 before falling back to 2.41 million ha in 2008.[13] Based on a conservative estimate of four fewer insecticide sprays being required for the cultivation of GM IR cotton relative to conventional cotton and applying this to the global area (excluding China and India) of GM IR cotton over the period 1996-2008 suggests that there has been a reduction of 119.6 million ha of cotton being sprayed. The cumulative saving in tractor fuel consumption has been 124.99 million liters. This represents a permanent reduction in carbon dioxide emissions of 344 million kg (Table 10).

Insect-resistant Maize

No analysis of the possible contribution to reduced level of carbon sequestration from the adoption of GM IR maize (via fewer insecticide spray runs) and the adoption of corn rootworm (CRW) resistant maize is presented. This is because the impact of using these technologies on carbon sequestration is likely to have been small for the following reasons.

- In some countries (e.g., Argentina), insecticide use for the control of pests such as the corn borer has traditionally been negligible.
- Even in countries where insecticide use for the control of corn-boring pests has been practiced (e.g., the United States), the share of the total crop treated has been fairly low (under 10% of the crop) and varies by region and year according to pest pressure.
- Nominal application savings have occurred in relation to the adoption of GM CRW maize where more than 13.7 million ha were planted in 2008. The adoption of the GM CRW may become increasingly important with wider adoption of NT cultivation systems due to the potential increase in soil-borne pests.

12. These are excluded because all spraying in these two countries is assumed to be undertaken by hand.

13. This is in line with the general fall in total cotton plantings.

Table 11. Summary of carbon sequestration impact 1996-2008.

Crop/trait/country	Permanent fuel saving (million liters)	Potential additional carbon dioxide saving from fuel saving (million kg)	Potential additional carbon dioxide saving from soil carbon sequestration (million kg)
US: GM HT soybeans	835	2,295	38,057
Argentina: GM HT soybeans	1,636	4,499	43,775
Other countries: GM HT soybeans	196	539	7,939
Canada: GM HT canola	347	955	11,842
Global GM IR cotton	125	344	0
Total	3,139	8,632	101,613

Note: Other countries: GM HT soybeans Paraguay and Uruguay (applying US carbon sequestration assumptions). Brazil not included because of NT/RT adoption largely in the absence of GM HT technology.

Discussion and Conclusions

The analysis of pesticide use changes arising from the adoption of biotech crops shows that there have been important environmental benefits, amounting to 352 million kg less pesticide use by growers (an 8.4% reduction in the amount of active ingredient applied). As weight of active ingredient applied is a fairly crude measure of environmental impact, the analysis considered impacts using an alternative (more rounded) measure, known as the EIQ. Based on this, the environmental benefits have been more significant at a 16.3% reduction in the environmental impact associated with insecticide and herbicide use on the global crop area planted to biotech traits (1996-2008). The most significant environmental benefits derived have been associated with the adoption of GM IR cotton, which has resulted in a substantial reduction in insecticide applications on cotton. There have also been important environmental gains associated with the adoption of GM HT technology, which has seen a switch to the use of more environmentally benign active ingredients.

The analysis also shows that biotechnology trait adoption has made important contributions to reducing GHG emissions associated with cropping agriculture, and a summary of the total carbon sequestration impact of GM crops is presented in Table 11. This shows that the permanent savings in carbon dioxide emissions (arising from reduced fuel use of 3,137 million liters of fuel) since 1996 have been about 8,632 million kg and the additional amount of soil carbon sequestered since 1996 has been equivalent to 101,613 million tonnes of carbon dioxide that has not been released into the global atmosphere.[14] The reader should, however, note that these soil carbon savings are based on saving arising from the rapid adoption of NT/RT farming systems in North and South America for which the availability of GM HT technology has been cited by many farmers as an important facilitator. GM HT technology has therefore probably been an important contributor to this increase in soil carbon sequestration but is not the only factor of influence. Other influences, such as the availability of relatively cheap generic glyphosate (the real price of glyphosate fell threefold between 1995 and 2000 once patent protection for the product expired), have also been important, as illustrated by the rapid adoption of NT/RT production systems in the Brazilian soybean sector, largely in the absence of the GM HT technology.[15] Cumulatively the amount of carbon sequestered may be higher than these estimates due to year-on-year benefits to soil quality; however, equally with only an estimated 15-25% of the crop area in continuous NT systems, it is likely that the total cumulative soil sequestration gains have been lower. Nevertheless, it is not possible to estimate cumulative soil sequestration gains that take into account reversions to conventional tillage because of the lack of detailed, disaggregated farm- and field-level tillage data for the

14. *These estimates are based on fairly conservative assumptions and therefore the true values could be higher. Also, some of the additional soil carbon sequestration gains from RT/NT systems may be lost if subsequent ploughing of the land occurs. Estimating the possible losses that may arise from subsequent ploughing would be complex and difficult to undertake. This factor should be taken into account when using the estimates presented in this section of the report.*

15. *The reader should note that the estimates of soil carbon sequestration savings presented do not include any for soybeans in Brazil because we have assumed that the increase in NT/RT area has not been primarily related to the availability of GM HT technology in Brazil.*

Table 12. Context of carbon sequestration impact 2008: Car equivalents.

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the permanent fuel savings	Potential additional soil carbon sequestration savings (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the potential additional soil carbon sequestration
US: GM HT soybeans	290	129	4,691	2,085
Argentina: GM HT soybeans	624	277	6,290	2,795
Other countries: GM HT soybeans	82	37	1,214	539
Canada: GM HT canola	179	80	2,223	988
Global GM IR cotton	28	12	0	0
Total	1,205	534	14,417	6,408

Note: Assumption: An average family car produces 150 grams of carbon dioxide of km. A car does an average of 15,000 km/year and therefore produces 2,250 kg of carbon dioxide/year.

1996-2008 period. Consequently, the estimate provided above of 101,613 million tonnes of carbon dioxide not released into the atmosphere should be treated with caution and clearly represents a potential maximum rather than a realized level.

Further examining the context of the carbon sequestration benefits, Table 12 shows the carbon dioxide equivalent savings associated with planting of biotech crops for the latest year (2008) in terms of the number of car-use equivalents. This shows that in 2008, the permanent carbon dioxide savings from reduced fuel use was the equivalent of removing nearly 0.534 million cars from the road for a year, and the additional soil carbon sequestration gains were equivalent to removing nearly 6.4 million cars from the roads. In total, biotech crop-related carbon dioxide emission savings in 2008 were equal to the removal from the roads of nearly 6.9 million cars, equal to about 26% of all registered private cars in the United Kingdom.

The impacts identified in this article are, however, probably conservative, reflecting the limited availability of relevant data and conservative assumptions used. In addition, the analysis examines only a limited number of environmental indicators. As such, subsequent research of the environmental impact might usefully include additional environmental indicators such as impact on soil erosion.

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Appendix A: Details of Methodology as Applied to 2008 Calculations of Environmental Impact Associated with Pesticide Use Changes

Table A1. GM IR corn (targeting corn-boring pests) 2008.

Country	Area of trait ('000 ha)	Maximum area treated for corn boring pests: Pre GM IR ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	18,140	3,182	0.23	0.83	12.8	32.8	-1,909	-63.6
Canada	750	60.2	0.04	0.64	4.8	24.8	-36.12	-1.25
Argentina	1,150	0	0	0	0	0	0	0
Philippines	280	Very low - assumed zero	0	0	0	0	0	0
South Africa	1,668	1,768	0	0.094	0	3.42	-156.8	-5.71
Spain	79.3	36.3	0.36	1.32	0.9	26.9	-34.9	-0.94
Uruguay	110	Assumed to be zero: as Argentina	0	0	0	0	0	0
Brazil	1,450	Not known	Not known	Not known	Not known	Not known	None applied	None applied

Note: Brazil: *2008 was first year of use of GM IR corn technology. Insufficient data currently available to make an assessment.* Other countries: *Honduras and EU countries: Areas planted to GM IR corn under 10,000 ha in each country: not examined.*

Table A2. GM IR corn (targeting corn rootworm) 2008.

Country	Area of trait ('000 ha)	Maximum area treated for corn boring pests: Pre GM IR ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	13,689	9,543	0.234	0.45	12.8	20.43	-2,063	-72.8

Note: There are no Canadian-specific data available. Analysis has therefore not been included for the Canadian crop of 119,000 ha planted to seed containing GM IR traits targeted at corn rootworm pests.

Table A3. GM IR cotton 2008.

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	1,930	0.92	1.06	29.1	38.0	-276.6	-17.1
China	3,828	1.84	2.80	83.22	127.96	-3,675	-171.3
Australia	121.2	2.2	11.0	39	220	-1,066.9	-21.94
Mexico	70	3.6	5.22	120.4	177.0	-113.5	-3.96
Argentina	213	0.64	1.15	21.0	53.0	-108.6	-6.82
India	6,973	1.06	1.86	34.43	70.07	-5,565.1	-248.5
Brazil	170	0.64	1.15	21.0	53.0	-86.7	-5.44

Note: Due to the widespread and regular nature of bollworm and budworm pest problems in cotton crops, GM IR areas planted are assumed to be equal to the area traditionally receiving some form of conventional insecticide treatment.
South Africa (7,700 ha), Burkino Faso (8,500 ha), and Columbia (28,000 ha) not included in analysis due to lack of data and small size of plantings relative to total area of trait.
Brazil: due to a lack of data, usage patterns from Argentina have been assumed.

Table A4. GM HT soybeans 2008.

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	27,790	1.63	1.62	26.29	36.16	+277.9	-274.3
Canada	880	1.32	1.43	20.88	34.20	-96.8	-11.73
Argentina	16,830	2.68	2.53	41.38	43.64	+2,524	-38.05
Brazil	13,320	2.37	1.94	36.34	32.96	+5,705	+45.0
Paraguay	2,430	1.16	0.99	18.8	20.05	+413.1	-3.04
South Africa	184	1.89	1.556	28.97	32.08	+61.4	-0.57
Uruguay	569	2.68	2.53	41.38	43.64	+85.4	-1.29
Mexico	7.3	1.62	1.76	24.83	41.02	-1	-0.12
Bolivia	454	1.16	0.99	18.8	20.05	+77.11	-0.57

Note: Due to lack of country-specific data, usage patterns in Paraguay assumed for Bolivia and usage in Argentina assumed for Uruguay.

Table A5. GM HT corn 2008.

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US glyphosate tolerant	18,847	2.06	3.48	43.08	77.15	-26,802	-642.0
US glufosinate tolerant	1,203	2.04	3.48	44.76	77.15	-1.738	-39.0
Canada glyphosate tolerant	477	1.83	2.71	37.01	61.10	-418.9	-11.44
Canada glufosinate tolerant	136	1.64	2.71	36.01	61.01	-145.3	-3.41
Argentina	805	2.36	2.77	43.80	57.82	-330.0	-11.3
South Africa	646	2.754	3.103	46.17	65.87	-225.3	-12.7

Note: The Philippines is not included due to lack of data on weed-control methods and product use.

Table A6. GM HT cotton 2008.

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	2,082.8	2.83	3.26	50.6	60.08	-896	-19.74
South Africa	11.0	1.80	1.81	27.59	31.86	-0.11	-0.05
Australia	122.5	4.0	6.29	67.28	113.50	-281.4	-5.66
Argentina	210	1.80	3.48	27.60	68.04	-358.7	-8.6

Note: Mexico is not included due to lack of data on herbicide use.

Table A7. GM HT canola 2008.

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/HA GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US glyphosate tolerant	180.1	0.649	1.12	9.95	25.71	-84.8	-2.84
US glufosinate tolerant	200.1	0.383	1.12	7.78	25.71	-147.5	-3.59
Canada glyphosate tolerant	2,943	0.7	0.56	10.68	11.52	+403.2	-2.47
Canada glufosinate tolerant	2,681	0.35	0.56	7.07	11.52	-569.1	-11.93

Table A8. GM herbicide-tolerant sugar beet 2008.

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	258	1.90	1.40	29.13	30.89	+129	-0.45

Appendix B: Examples of EIQ Calculations

Table B1. Estimated typical herbicide regimes for conventional reduced/no till soybean production systems that will provide an equal level of weed control to the GM HT system in Argentina 2008.

	Active ingredient	Field eiq/ha
	Option 1	
Glyphosate	0.864	13.25
Metsulfuron	0.03	0.50
2 4 d amine	0.3	6.21
Imazethapyr	0.08	1.57
Diflufenican	0.05	0.88
Clethodim	0.144	2.45
Total	**1.468**	**24.85**
	Option 2	
Glyphosate	1.35	20.70
Dicamba	0.0576	1.46
Acetochlor	1.08	21.49
haloxifop *	0.096	2.13
Sulfentrazone	0.0875	1.02
Total	**2.67**	**46.80**
	Option 3	
Glyphosate	1.62	24.83
Atrazine	0.384	8.79
Bentazon	0.6	11.22
2 4 db ester	0.04	0.61
Imazaquin	0.024	0.37
Total	**2.67**	**45.83**
	Option 4	
Glyphosate	1.8	27.59
2 4 d amine	0.384	7.95
Flumetulam	0.06	0.94
Fomesafen	0.25	6.13
Chlorimuron	0.015	0.29
Fluazifop	0.12	3.44
Total	**2.63**	**46.34**
	Option 5	
Glyphosate	1.8	27.59
Metsulfuron	0.05	0.84
2 4 d amine	0.75	15.53
Imazethapyr	0.1	1.96
haloxifop	0.096	2.13
Total	**2.80**	**48.05**
	Option 6	
Glyphosate	1.8	27.59
Metsulfuron	0.05	0.84
2 4 d amine	0.75	15.53
Imazethapyr	0.1	1.96
Clethodim	0.24	4.08
Total	2.94	49.99
Average all	**2.53**	**43.64**

Sources: AAPRESID (Argentine No-Till Farmers Association, personal communication) and Monsanto Argentina (personal communications, 2006, 2007, & 2009).

Table B2. GM HT soybeans Argentina 2008.

	Active ingredient (kg/ha)	Field eiq/ ha value
Derived from AMIS Global farm survey market research data	2.68	41.38

Table B3. GM HT versus conventional corn Argentina 2008.

	Active ingredient (kg/ha)	Field eiq/ha value
Conventional		
	Option 1	
Acetechlor	1.68	33.43
Atrazine	1.0	22.90
Misotrione	0.14	2.52
Total	**2.82**	**58.85**
	Option 2	
Acetechlor	1.68	33.43
Atrazine	1.0	22.90
Foramsulam	0.03	0.46
Total	**2.71**	**56.79**
Average conventional	2.77	57.82
GM HT corn		
Acetochlor	0.84	16.72
Atrazine	0.5	11.45
Glyphosate	1.02	15.64
Total	**2.36**	**43.80**

Sources: AMIS Global and Monsanto Argentina (personal communication).

Table B4. Typical herbicide regimes for GM HT soybeans in South Africa.

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional soybeans		
	Option 1	
Alochlor	1.536	27.49
Chlorimuron	0.01	0.19
Total	**1.546**	**27.69**
	Option 2	
S Metalochlor	1.536	33.79
Imazethapyr	0.07	0.78
Total	**1.576**	**34.58**
	Option 3	
S Metalochlor	1.536	33.79
Chlorimuron	0.01	0.78
Total	1.546	34.58
Average	1.556	32.08
GM HT soybeans		
Glyphosate	1.89	28.97

Source: Monsanto South Africa (personal communication).

Table B5. Typical herbicide regimes for GM HT maize in Canada.

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional maize		
Metalochlor	1.3566	29.84
Atrazine	1.1912	27.28
Primsulfuron	0.0244	0.41
Dicamba	0.14	3.54
Total	**2.7122**	**61.07**
GM glyphosate-tolerant maize		
Metalochlor	0.678	14.92
Atrazine	0.594	13.60
Glyphosate	0.56	8.58
Total	**1.832**	**37.10**
GM glufosinate-tolerant maize		
Metalochlor	0.678	14.92
Atrazine	0.594	13.60
Glufosinate	0.37	7.49
Total	**1.642**	**36.01**

Sources: Ontario Ministry of Agriculture, Food, and Rural Affairs (2002), industry (personal communication with various seed industry sources).

Table B6. Typical insecticide regimes for cotton in India 2008.

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
	Option 1	
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Triazophos	0.5	17.80
Profenfos	0.625	37.19
Acephate	0.6	14.94
Spinosad	0.384	5.53
Metaflumizone	0.025	0.82
Flubendiamide	0.048	0.93
Total	**2.42**	**84.15**
	Option 2	
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Profenfos	0.625	37.19
Chloripyrifos	0.4	10.76
Metaflumizone	0.025	0.82
Emamectin	0.011	0.29
Total	**1.30**	**56.00**
Average conventional	1.86	70.07
GM IR cotton		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Triazophos	0.5	17.80
Profenfos	0.625	37.19
Total	**1.36**	**61.92**
	Option 2	
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Total	**0.24**	**6.94**
Average GM IR cotton	1.06	34.43

Source: Monsanto India (personal communication).

Table B7. Data sources (for pesticide usage data).

	Sources of data for assumptions
US	Gianessi and Carpenter (1999) Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007) All of the above mainly for conventional regimes (based on surveys of extension advisors across the United States) DMR Kynetec—private market research data on pesticide usage. Is the most comprehensive dataset on crop pesticide usage at the farm level and allows for disaggregation to cover biotech versus conventional crops. This source primarily used for usage on biotech traits.
Argentina	AMIS Global—private market research data on pesticide use. Is the most detailed dataset on crop pesticide use. AAPRESID (farmer producers association)—personal communication (2007) Monsanto Argentina (personal communication, 2005, 2007, 2009) Qaim and De Janvry (2005) Qaim and Traxler (2002)
Brazil	AMIS Global Galveo (2009) and personal communication Monsanto Brazil (2008) Monsanto Brazil (personal communication, 2007, 2009)
Uruguay	As Argentina: No country-specific data identified
Paraguay	As Argentina for conventional soybeans (over-the-top usage), AMIS Global for GM HT soybeans
Bolivia	As Paraguay: No country-specific data identified
Canada	George Morris Centre (2004) Canola Council of Canada (2001) Gusta, Smyth, Belcher, Phillips, and Castle (2009) Ontario Ministry of Agriculture, Food, & Rural Affairs (2002 and updated annually)
South Africa	Monsanto South Africa (personal communication, 2005, 2007, 2009) Ismael, Bennett, Morse, and Buthelezi (2002)
Romania	Brookes (2005)
Australia	Doyle et al. (2003) Commonwealth Scientific and Industrial Research Organisation (CSIRO, 2005) Monsanto Australia (personal communication, 2005, 2007, 2009)
Spain	Brookes (2003, 2008)
China	Pray et al. (2002) Monsanto China (personal communication, 2007, 2009)
Mexico	Monsanto Comercial Mexico (2005, 2007, 2008) Traxler, Godoy-Avilla, Falck-Zepeda, and Espinoza-Arellano (2001)
India	Asia-Pacific Consortium on Agricultural Biotechnology (APCOAB, 2006) IMRB International (2007) Monsanto India (personal communication, 2007, 2008, 2009)

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Global Impact of Biotech Crops: Income and Production Effects, 1996-2007

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This article updates the assessment of the impact of commercialized agricultural biotechnology on global agriculture from an economic perspective. It examines specific global economic impacts on farm income, indirect (non-pecuniary) farm-level income effects and impacts on the production base of the four main crops—soybeans, corn, cotton, and canola. The analysis shows that there have been substantial net economic benefits at the farm level, amounting to $10.1 billion in 2007 and $44.1 billion for the 12-year period (in nominal terms). The non-pecuniary benefits associated with the use of the technology have also had a positive impact on adoption (in the US accounting for the equivalent of 25% of the total direct farm income benefit). Biotech crops have also made important contributions to increasing global production levels of the four main crops—adding, for example, 68 million tonnes and 62 million tonnes respectively to global production of soybeans and corn.

Key words: yield, cost, income, non-pecuniary benefit, production, biotech crops.

Introduction

This article presents the findings of research on the global economic impact of GM crops since their commercial introduction in 1996. It updates part of the findings of earlier analysis presented by the authors in *AgBioForum* 8(2&3), 9(3), and 11(1).[1]

The analysis concentrates on farm income effects because this is a primary driver of adoption amongst farmers (both large commercial and small-scale subsistence). It also considers more indirect farm income or non-pecuniary benefits, and quantifies the (net) production impact of the technology.

Methodology

The report is based largely on extensive analysis of existing farm-level impact data for biotech crops. While primary data for impacts of commercial cultivation were not available for every crop, in every year, and for each country, a substantial body of representative research and analysis is available, and this has been used as the basis for the analysis presented.

Since the economic performance and impact of this technology at the farm level varies widely—both between, and within regions/countries (as applies to any technology used in agriculture)—the measurement of performance and impact is considered on a case-by-case basis in terms of crop and trait combinations. The analysis presented is based on the average performance and impact recorded in different crops by the studies reviewed; the average performance is the most common way in which the identified literature has reported impact. Where several pieces of relevant research (e.g., on the impact of using a GM trait on the yield of a crop in one country in a particular year) have been identified, the findings used have been based largely on the average of these findings.

This approach may both overstate and understate the real impact of GM technology for some trait, crop, and country combinations, especially in cases where the technology has provided yield enhancements. However, since impact data for every trait, crop, location, and year is not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. Therefore, the authors acknowledge that this represents a weakness in the research. To reduce the possibilities of over/understating impact, the analysis:

- directly applies impacts identified from the literature to the years that have been studied. As a result, the impacts used vary in many cases according to the findings of literature covering different years.[2] Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing

1. *Readers should note that some data presented in this article are not directly comparable with data presented in the previous three articles because the current articles takes into account the availability of new data and analysis (including revisions to data for earlier years).*

with (annual) fluctuations in pest and weed infestation levels as identified by research;
- uses current farm-level crop prices and bases any yield impacts on (adjusted—see below) current average yields. In this way some degree of dynamics has been introduced into the analysis that would otherwise be missing if constant prices and average yields indentified in year-specific studies had been used;
- includes some changes and updates to the impact assumptions identified in the literature based on consultation with local sources (analysts, industry representatives) so as to better reflect prevailing/changing conditions (e.g., pest and weed pressure, cost of technology);
- includes some sensitivity analysis in which the impacts based on average performance are supplemented by a range incorporating 'below average' and 'above average' performance assumptions (see Appendix 2 for details); and
- adjusts downward the average base yield (in cases where GM technology has been identified as having delivered yield improvements) on which the yield enhancement has been applied. In this way, the impact on total production is not overstated.

Detailed examples of how the methodology has been applied to the calculation of the 2007 year results are presented in Appendix 1. Appendix 2 also provides details of the impacts and assumptions applied and their sources.

Other aspects of the methodology used to estimate the impact on direct farm income are as follows.

- Impact is quantified at the trait and crop level, including where stacked traits are available to farmers. Where stacked traits have been used, the individual trait components were analyzed separately to ensure estimates of all traits were calculated.
- All values presented are nominal for the year shown and the base currency used is the US dollar. All financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year.
- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure, but also impact on costs such as fuel and labor),[3] crop quality (e.g., improvements in quality arising from less pest damage or lower levels of weed impurities, which result in price premia being obtained from buyers), and the scope for facilitating the planting of a second crop in a season (e.g., second crop soybeans in Argentina following wheat that would, in the absence of the GM herbicide-tolerant [HT] seed, probably not have been planted). Thus, the farm income effect measured is essentially a gross margin impact (impact on gross revenue less variable costs of production) rather than a full net cost of production assessment. Through the inclusion of yield impacts and the application of actual (average) farm prices for each year, the analysis also indirectly takes into account the possible impact of biotech crop adoption on global crop supply and world prices.

The article also examines some of the more intangible (more difficult to quantify) economic impacts of GM technology. The literature in this area is much more limited and, in terms of aiming to quantify these impacts, largely restricted to the US-specific studies. The findings of this research are summarized[4] and extrapolated to the cumulative biotech crop planted areas in the United States in the 1996-2007 period.

Lastly, the article includes estimates of the production impacts of GM technology at the crop level. These have been aggregated to provide the reader with a global perspective of the broader production impact of the technology. These impacts derive from the yield impacts (where identified), but also from the facilitation of addi-

2. *Examples where such data is available include the impact of GM insect-resistant cotton: in India, see Bennett, Ismael, Kambhampati, and Morse (2004) and IMRB (2006, 2007); in Mexico, see Traxler, Godoy-Avilla, Falck-Zepeda, and Espinoza-Arellano (2001) and Monsanto Mexico (2005, 2007); and in the US, see Sankula and Blumenthal (2003, 2006) and Mullins and Hudson (2004).*

3. *Impacts on these categories of cost are, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analyses. Therefore, in most cases the analysis relates to impact of crop protection and seed cost only.*

4. *Notably relating to the US—Marra and Piggott (2006).*

Table 1. Global farm income benefits from growing biotech crops, 1996-2007 (US $ million).

Trait	2007 increase in farm income	1996-2007 increase in farm income	2007 farm income benefit as % of total value of production of these crops in biotech adopting countries	2007 farm income benefit as % of total value of global production of crop
GM HT soybeans	3,935.5	21,814.1	7.2	6.4
GM HT maize	442.3	1,507.6	0.7	0.4
GM HT cotton	24.5	848.2	0.1	0.1
GM HT canola	345.6	1,438.6	7.65	1.4
GM IR maize	2,075.3	5,673.6	3.2	1.9
GM IR cotton	3,204.0	12,576.2	16.5	10.2
Others	54.4	208.8	n/a	n/a
Totals	**10,081.6**	**44,067.1**	**6.9**	**4.4**

Note. All values are nominal. Others = Virus-resistant papaya and squash. Totals for the value shares exclude "other crops" (i.e., relate to the four main crops of soybeans, maize, canola, and cotton). Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality, and key variable costs of production (e.g., payment of seed premia, impact on crop protection expenditure).

tional cropping within a season (notably in relation to soybeans in South America). Details of how these values were calculated (for 2007) are shown in Appendix 1.

Results

GM technology has had a significant positive impact on farm income derived from a combination of enhanced productivity and efficiency gains (Table 1). In 2007, the direct global farm income benefit from biotech crops was $10.1 billion. This is equivalent to having added 4.4% to the value of global production of the four main crops of soybeans, maize, canola, and cotton. Since 1996, farm incomes have increased by $44.1 billion.

The largest gains in farm income have arisen in the soybean sector, largely from cost savings. The $3.9 billion additional income generated by GM HT soybeans in 2007 has been equivalent to adding 7.2% to the value of the crop in biotech-growing countries, or adding the equivalent of 6.4% to the $60 billion value of the global soybean crop in 2007. These economic benefits should, however be placed within the context of a significant increase in the level of soybean production in the main biotech-adopting countries. Since 1996, the soybean area in the leading soybean-producing countries—United States, Brazil, and Argentina—increased by 58%.

Substantial gains also have arisen in the cotton sector through a combination of higher yields and lower costs. In 2007, cotton farm income levels in the biotech-adopting countries increased by $3.2 billion, and since 1996, the sector has benefited from an additional $12.6 billion. The 2007 income gains are equivalent to adding 16.5% to the value of the cotton crop in these countries, or 10.2% to the $27.5 billion value of total global cotton production. This is a substantial increase in value-added terms for two new cotton seed technologies.

Significant increases to farm incomes have also occurred in the maize and canola sectors. The combination of GM insect-resistant (GM IR) and GM HT technology in maize has boosted farm incomes by $7.2 billion since 1996. In the North American canola sector, an additional $1.4 billion has been generated.

Table 2 summarizes farm income impacts in key biotech-adopting countries. This highlights the important farm income benefit arising from GM HT soybeans in South America (Argentina, Brazil, Paraguay, and Uruguay), GM IR cotton in China and India, and a range of GM cultivars in the United States. It also illustrates the growing level of farm income benefits being obtained in South Africa, the Philippines, and Mexico.

In terms of the division of the economic benefits obtained by farmers in developing countries relative to farmers in developed countries, Table 3 shows that in 2007, 58% of the farm income benefits were earned by developing-country farmers. The vast majority of these income gains for developing-country farmers have been from GM IR cotton and GM HT soybeans.[5] Over the twelve years—1996-2007—the cumulative farm income gain derived by developing country farmers was $22.1 billion (50.1% of the total).

Examining the cost farmers pay for accessing GM technology, Table 4 shows that across the four main bio-

5. *The authors acknowledge that the classification of different countries into developing or developed country status affects the distribution of benefits between these two categories of country. The definition used in this article is consistent with the definition used by James (2007).*

Table 2. GM crop farm income benefits in selected countries, 1996-2007 ($ million).

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
US	10,422	1,402.9	804	149.2	4,778.9	2,232.7	19,789.7
Argentina	7,815	46	28.6	n/a	226.8	67.9	8,184.3
Brazil	2,868	n/a	n/a	n/a	n/a	65.5	2,933.5
Paraguay	459	n/a	n/a	n/a	n/a	n/a	459
Canada	103.5	42	n/a	1,289	208.5	n/a	1,643
South Africa	3.8	5.2	0.2	n/a	354.9	19.3	383.4
China	n/a	n/a	n/a	n/a	n/a	6,740.8	6,740.8
India	n/a	n/a	n/a	n/a	n/a	3,181.0	3,181.0
Australia	n/a	n/a	5.2	n/a	n/a	190.6	195.8
Mexico	8.8	n/a	10.3	n/a	n/a	65.9	85
Philippines	n/a	11.4	n/a	n/a	33.2	n/a	44.6
Romania	92.7	n/a	n/a	n/a	n/a	n/a	92.7
Uruguay	42.4	n/a	n/a	n/a	2.7	n/a	45.1
Spain	n/a	n/a	n/a	n/a	60.0	n/a	60
Other EU	n/a	n/a	n/a	n/a	8.6	n/a	8.6
Colombia	n/a	n/a	n/a	n/a	n/a	12.6	12.6

Note. All values are nominal. Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality, and key variable costs of production (e.g., payment of seed premia, impact on crop protection expenditure). n/a = not applicable. US figures exclude benefits from virus-resistant crops.

Table 3. GM crop farm income benefits in developing versus developed countries, 2007 ($ million).

	Developed	Developing
GM HT soybeans	1,375.1	2,560.5
GM IR maize	1,773.4	301.9
GM HT maize	401.6	40.8
GM IR cotton	285.8	2,918.1
GM HT cotton	16.3	8.2
GM HT canola	345.6	0
GM virus-resistant papaya and squash	54.4	0
Total	**4,252.2**	**5,829.5**

Note. Developing countries = all countries in South America, Mexico, India, China, the Philippines, and South Africa.

tech crops, the total cost in 2007 was equal to 24% of the total technology gains (inclusive of farm income gains plus the cost of the technology payable to the seed supply chain).[6]

For farmers in developing countries the total cost was equal to 14% of total technology gains, while for farmers in developed countries the cost was 34% of the total technology gains. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income gains in developing countries relative to the farm income share in developed countries reflects factors such as weaker provision and enforcement of intellectual property rights in developing countries and the higher average level of farm income gain on a per-hectare basis derived by developing country farmers relative to developed country farmers.

As indicated in the methodology section, the analysis presented above is largely based on estimates of average impact in all years. Recognizing that pest and weed pressure varies by region and year, additional sensitivity analysis was conducted for the crop/trait combinations where yield impacts were identified in the literature. This sensitivity analysis (see Appendix 2 for details) was undertaken for two levels of impact assumption: one in which all yield effects in all years were assumed to be 'lower than average' (levels of impact that reflected yield impacts in years of low pest/weed pressure), and one in which all yield effects in all years were assumed to be 'higher than average' (levels of impact that reflected yield impacts in years of high pest/weed pressure). The results of this analysis suggest a range of positive direct farm income gains in 2007 of +$8.5 to +$12.9 billion and, over the 1996-2007 period, a range of +$38.2 to +$52.2 billion (Table 5). This range

6. *The cost of the technology accrues to the seed supply chain, including sellers of seed to farmers, seed multipliers, plant breeders, distributors, and the GM technology providers.*

Table 4. Cost of accessing GM technology relative to the total farm income benefits, 2007 ($ million).

	Cost of technology: All farmers	Farm income gain: All farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology: Developing countries	Farm income gain: Developing countries	Total benefit of technology to farmers and seed supply chain: Developing countries
GM HT soybeans	930.8	3,935.5	4,866.3	326	2,560.5	2,886.5
GM IR maize	714.3	2,075.3	2,789.6	79.1	301.9	381
GM HT maize	530.8	442.3	973.1	20.2	40.8	61
GM IR cotton	670.4	3,204.0	3,874.4	535.1	2,918.1	3,453.2
GM HT cotton	226.4	24.5	250.9	8.5	8.2	16.7
GM HT canola	102.2	345.6	447.8	n/a	n/a	n/a
Total	**3,174.9**	**10,027.2**	**13,202.1**	**968.9**	**5,829.5**	**6,798.4**

Note. n/a = not applicable. Cost of accessing technology based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents. Total farm income gain excludes $54.4 million associated with virus-resistant crops in the United States.

Table 5. Direct farm income benefits 1996-2007 under different impact assumptions ($ million).

Crop	Consistent below average pest/weed pressure	Average pest/weed pressure (main study analysis)	Consistent above average pest/weed pressure
Soybeans	21,796.0	21,814.1	21,829.0
Corn	4,571.0	7,181.2	12,152.0
Cotton	10,920	13,424.4	15,962.0
Canola	818.7	1,438.6	2,013.0
Others	101.4	208.8	224.3
Total	**38,207.1**	**44,067.1**	**52,180.3**

Note. No significant change to soybean production under all three scenarios as almost all gains due to cost savings and second crop facilitation.

is broadly within 85% to 120% of the main estimates of farm income presented above.

Indirect (Non-Pecuniary) Farm-Level Impacts

In addition to the tangible and quantifiable impacts on farm profitability presented above, there are other important, more intangible (difficult to quantify) impacts of an economic nature.

Many of the studies[7] of the impact of biotech crops have identified the following reasons as being important influences for adoption of the technology.

Herbicide Tolerant Crops

- HT crops allow for increased management flexibility and convenience that comes from a combination of the ease of use associated with broad-spectrum, post-emergent herbicides like glyphosate and the increased/longer time window for spraying. This not only frees up management time for other farming activities but also allows additional scope for undertaking off-farm, income-earning activities.
- In a conventional crop, post-emergent weed control relies on herbicide applications before the weeds and crop are well established. As a result, the crop may suffer 'knock-back' to its growth from the effects of the herbicide. In the GM HT crop, this problem is avoided because the crop is both tolerant to the herbicide and spraying can occur at a later stage when the crop is better able to withstand any possible "knock-back" effects.
- These crops facilitate the adoption of conservation or no-tillage systems. This provides for additional cost savings such as reduced labor and fuel costs associated with plowing, additional moisture retention, and reductions in soil erosion levels.
- Improved weed control has contributed to reduced harvesting costs—cleaner crops have resulted in reduced times for harvesting. It has also improved harvest quality and led to higher levels of quality price bonuses in some regions and years (e.g., HT soybeans and HT canola in the early years of adoption, respectively, in Romania and Canada).
- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on

7. *For example, relating to HT soybeans, USDA (1999), Gianessi and Carpenter (1999), and Qaim and Traxler (2002); relating to IR maize, Rice (2004) and Brookes (2008); relating to IR cotton, Ismael, Bennett, Morse, and Buthelezi (2002) and Pray et al. (2002).*

crops and less need to apply herbicides in a follow-on crop because of the improved levels of weed control;
- HT crops also contribute to a general improvement in human safety (as manifest in greater peace of mind about own and worker safety) from reduced exposure to herbicides and a switch to more environmentally benign products.

Insect Resistant Crops

- IR crops offer benefits in the areas of production risk management and insurance. The technology takes away much of the worry of significant pest damage occurring and is, therefore, highly valued. Although not applicable in 2007 (piloted in 2008 and likely to be more widely operational from 2009), US farmers using stacked corn traits (containing IR and HT traits) are being offered discounts on crop insurance premiums equal to $7.41/hectare.
- These crops have a 'convenience' benefit derived from having to devote less time to crop walking and/or applying insecticides.
- IR crops offer savings in energy use—mainly associated with less use of aerial spraying and less tillage.
- Planting IR crops can produce savings in machinery use (for spraying and possibly reduced harvesting times).
- IR crops produce a higher quality of crop. There is a growing body of research evidence relating to the superior quality of GM IR corn relative to conventional and organic corn from the perspective of having lower levels of mycotoxins. Evidence from Europe (as summarized in Brookes [2008]) has shown a consistent pattern in which GM IR corn exhibits significantly reduced levels of mycotoxins compared to conventional and organic alternatives. In terms of revenue from sales of corn, however, no premia for delivering product with lower levels of mycotoxins have been reported to date; however, where the adoption of the technology has resulted in reduced frequency of crops failing to meet maximum permissible fumonisin levels in grain maize (e.g., in Spain), this delivers an important economic gain to farmers selling their grain to the food-using sector. In one study (Yorobe, 2004), GM IR corn farmers in the Philippines have also been reported to have obtained price premia of 10% relative to conventional corn because of better quality, less damage to cobs, and lower levels of impurities.
- They also offer improved health and safety for farmers and farm workers—from reduced handling and use of pesticides, especially in developing countries where many apply pesticides with little or no use of protective clothing and equipment.
- Shorter growing seasons (e.g., for some cotton growers in India) allow some farmers to plant a second crop in the same season.[8] Also, some Indian cotton growers have reported benefits for bee keepers, as fewer bees are now lost to insecticide spraying.

Some of the economic impact studies have attempted to quantify some of these benefits. For example, Qaim and Traxler (2002) quantified some of these in Argentina—a $3.65/hectare saving (-7.8%) in labor costs and a $6.82/ha (-28%) saving in machinery/fuel costs associated with the adoption of GM HT soybeans. Where identified, these cost savings have been included in the analysis presented above. Nevertheless, it is important to recognize that these largely intangible benefits are considered by many farmers as a primary reason for adoption of GM technology, and in some cases farmers have been willing to adopt for these reasons alone, even when the measurable impacts on yield and direct costs of production suggest marginal or no direct economic gain.

Since the early 2000s, a number of farmer-survey-based studies in the United States have also attempted to better quantify these non-pecuniary benefits. These studies have usually employed contingent valuation techniques[9] to obtain farmer valuations of non-pecuniary benefits.

- A 2002 survey of 600 US corn farmers explored opinions and valuations of the then new IR corn trait resistant to corn rootworm, which was introduced in the following year (2003). Respondents were asked to value any potential time and equipment savings, additional farmer and worker

8. *Notably maize in India.*
9. *Survey-based method of obtaining valuations of non-market goods that aim to identify willingness to pay for specific goods (e.g., environmental goods, peace of mind, etc.) or willingness to pay to avoid something being lost.*

safety, additional environmental benefits, and production risk management benefits (from more consistent control of rootworm) that they thought might arise from use of the technology relative to existing corn rootworm control methods. The production risk management benefit was mostly highly valued by farmers, followed by operator/worker safety and environmental gains. The average value of all the non-pecuniary benefits was $17.89/hectare for likely adopters, $9.54/hectare for unlikely adopters, and an overall average of $16.33/hectare across all farmers surveyed.

- A 2002 survey of 610 US soybean farmers sought farmers' views on the benefits associated with their use (since 1996) of GM HT soybeans. Respondents were asked to value additional farmer and worker safety, the environmental impact of the technology and the additional convenience and flexibility the technology provided for weed control relative to the conventional alternatives. All of these benefits were valued by the soybean farmers, with convenience given the highest value. Overall, the average benefit attributed to these three categories of non-pecuniary benefits was $27/hectare (58% of which came from the convenience benefit).
- A 2003 survey of nearly 300 farmers of GM HT crops (soybeans, corn, and cotton) asked respondents to value additional farmer and worker safety, the environmental impact of the technology, and the additional convenience and flexibility the technology provided for weed control relative to the conventional alternatives. Results obtained were similar to those in the 2002 soybean farmer survey referred to above. In terms of valuations, the average benefit attributed to these three categories of non-pecuniary benefits were, respectively, $32/hectare for HT corn farmers, $35.70/hectare for HT soybean farmers, and $39.40/hectare for HT cotton farmers.

The values for non-pecuniary benefits identified in these surveys are, however, usually subject to bias due to factors such as the hypothetical nature of the contingent valuation technique, the framing of questions, and what is referred to as part-whole bias.[10] Marra and Piggott (2006) examined bias (notably part-whole bias) in the three surveys referred to above and found most respondents tended to overstate the value of parts by more than 60% compared with the separately stated total values for all non-pecuniary benefits. They subsequently rescaled[11] the sum of the values given by respondents to each separate non-pecuniary benefit and identified revised average (median) values for the non-pecuniary benefits in each survey (Table 6). This suggests that US farmers who make widespread use of biotech HT traits value the non-pecuniary benefits of the technology at between $12.35/hectare and $24.71/hectare, with cotton farmers valuing the non-pecuniary aspects highest and corn farmers having the lowest valuation. In terms of attributes most valued, convenience is perceived to provide between 50% and 66% of the total non-pecuniary benefit of the HT technology. It is also interesting to note that the most recent survey of cotton farmers using HT (flex) technology have valued this technology as delivering an additional $12/hectare in tterms of benefit from extra convenience relative to the first generation of biotech HT cotton technology. Corn producers value the non-pecuniary benefits of the IR ((rootworm resistance) technology at about $7.40/hectare, of which the risk reduction component accounted for the largest single share (about a third).

Table 6. Re-scaled values of non-pecuniary benefits.

Survey	Median value ($/hectare)
2002 IR (to rootworm) corn growers survey	7.41
2002 soybean (HT) farmers survey	12.35
2003 HT cropping survey (corn, cotton & soybeans)—North Carolina	24.71
2006 HT (flex) cotton survey	12.35 (relative to first generation HT cotton)

Source: Marra and Piggot (2006, 2007).

Aggregating the Impact to US Crops 1996-2007

The approach used to estimate the non-pecuniary benefits derived by US farmers from biotech crops over the period 1996-2007 has been to draw on the re-scaled values identifed by Marra and Piggot (2006, 2007, Table 6) and to apply these to the biotech-crop planted areas during this 12-year period. Figure 1 summarizes the values for non-pecuniary benefits derived from biotech crops

10. In the case of non-pecuniary benefits, the sum of values given by farmers to individual categories of benefit is greater than their stated total value of all non-pecuniary benefits (farmers being asked to value each type of benefit separately in addition to separately valuing total non-pecuniary benefits).

11. See Marra and Piggott (2006).

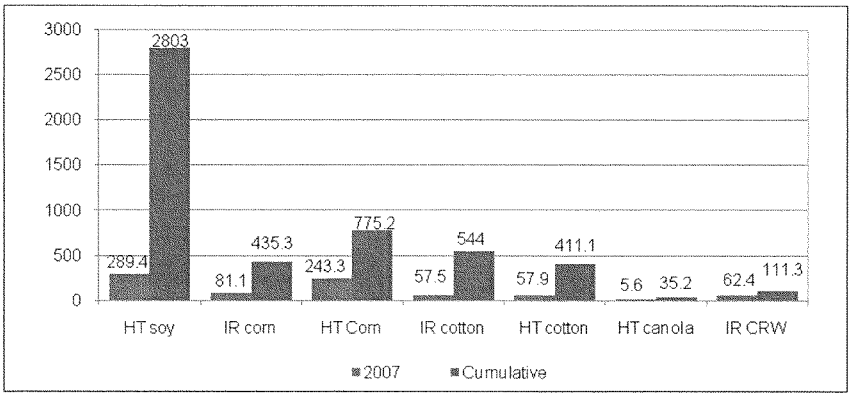


Figure 1. Non-pecuniary benefits derived by US farmers by trait, 1996-2007 ($ million).

in the United States (1996-2007) and shows an estimated (nominal value) benefit of $792 million in 2007 and a cumulative total benefit (1996-2007) of $5.11 billion. Relative to the value of direct farm income benefits presented above, the non-pecuniary benefits were equal to 21% of the total direct income benefits in 2007 and 25% of the total cumulative (1996-2007) direct farm income. This highlights the important contribution this category of benefit has had on biotech trait adoption levels in the United States, especially where the direct farm income benefits have been identfied to be relatively small (e.g., HT cotton).

Estimating the Impact in Other Countries

It is evident from the literature review that GM technology-using farmers in other countries also value the technology for a variety of non-pecuniary/intangible reasons. The most appropriate methodology for identifying these non-pecuniary benefit valuations in other countries would be to repeat the type of US farmer surveys in other countries. Unfortunately, the authors are not aware of any such studies undertaken to date.

Production Effects of the Technology

Based on the yield assumptions used in the direct farm income benefit calculations presented above (see Appendix 1) and taking into account the second soybean crop facilitation in South America, biotech crops have added important volumes to global production of corn, cotton, canola, and soybeans since 1996 (Table 7).

Table 7. Additional crop production arising from positive yield effects of biotech crops.

	1996-2007 additional production (million tonnes)	2007 additional production (million tonnes)
Soybeans	67.80	14.46
Corn	62.42	15.08
Cotton	6.85	2.01
Canola	4.44	0.54

The biotech IR traits—used in the corn and cotton sectors—have accounted for 99% of the additional corn production and almost all of the additional cotton prodduction. Positive yield impacts from the use of this technology have occurred in all user countries (except GM IR cotton in Australia)[12] when compared to average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). Since, 1996 the average yield impact across the total area planted to these traits over the 12 year period has been +6.1% for corn traits and +13.4% for cotton traits (Figure 2).

Although the primary impact of biotech HT technology has been to provide more cost-effective (less expensive) and easier weed control—versus improving yields

12. This reflects the levels of Heliothis pest control previously obtained with intensive insecticide use. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings (on insecticides) and the associated environmental gains from reduced insecticide use.

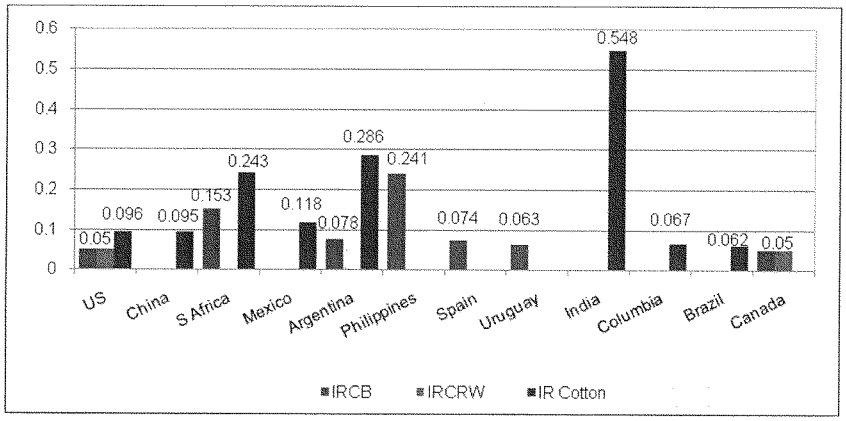


Figure 2. Average yield impact of biotech IR traits by country and trait, 1996-2007.
Note. IRCB = resistant to corn-boring pests. IRCRW = resistant to corn rootworm.

Table 8. Additional crop production arising from positive yield effects of biotech crops under different pest/weed pressure assumptions and impacts of the technology, 1996-2007 (million tonnes).

Crop	Consistent below average pest/weed pressure	Average pest/ weed pressure (main study analysis)	Consistent above average pest/weed pressure
Corn	46.0	62.42	109.5
Cotton	4.61	6.86	9.03
Canola	2.09	4.44	6.26

Note. No significant change to soybean production under all three scenarios as 99% of production gain due to second cropping facilitation of the technology.

from better weed control (relative to weed control obtained from conventional technology)—improved weed control has, nevertheless occurred, delivering higher yields in some countries. Specifically, HT soybeans in Romania improved the average yield by more than 30%, and biotech HT corn in Argentina and the Philippines delivered yield improvements of +9% and +15%, respectively.

Biotech HT soybeans have also facilitated the adoption of no-tillage production systems, shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 67.5 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2006—accounting for 99% of the total biotech-related additional soybean production.

Using the same sensitivity analysis as applied to the farm income estimates presented above to the production impacts (one scenario of consistent lower-than-average pest/weed pressure and one of consistent higher-than-average pest/weed pressure), Table 8.

Concluding Comments

This study quantified the cumulative global impact of GM technology between 1996 and 2007 on farm income and production. The analysis shows that there have been substantial direct economic benefits at the farm level, amounting to a cumulative total of $44.1 billion; half of this has been derived by farmers in developing countries. Important non-pecuniary benefits have also been derived by many farmers, which in the case of US farmers added a further $5.1 billion to the farm income benefits derived from the technology. GM technology has also resulted in additional production of important crops, equal to an extra 68 million tonnes of soybeans and 62 million tonnes of corn (1996-2007).

The impacts identified are based on estimates of average impact, reflecting the limitations of the methodologies used and the limited availability of relevant data.

Applying alternative assumptions that reflect the extremes of low weed and pest pressure in all years and high weed and pest pressure in all years suggests that the impact on farm income probably falls within a range of -15% to +20% around the cumulative estimate of $44.1 billion referred to above. Subsequent research at the trait- and country-level might usefully extend this analysis to incorporate more sophisticated consideration of dynamic economic impacts and broader (outside the United States) examination of the less tangible (non-pecuniary) economic impacts.

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Appendix 1: Details of Methodology as Applied to 2007 Farm Income Calculations

Table A1. GM IR corn (targeting corn boring pests), 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/ tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
United States	18,561	+5	9.25	135.4	-17.3	-1.42	61.22	+1,136,212	+8,584.4
Canada	831	+5	8.29	165.44	-19.3	+1.68	+70.26	+58,382	+344.4
Argentina	2,509	+5.5	6.8	113.0	-19.9	-19.9	+22.41	+56,220	+938.4
Philippines	194	+24.15	2.52	215.12	-36.2	-22.14	+108.78	+21,091	+118
South Africa	1,234	+15	4.0	304.47	-16.19	-2.29	+180.39	+222,601	+740.4
Spain	75.1	+10	9.34	283.77	-47.75	+9.55	+274.59	+20,634	+70.2
Uruguay	105	+5.5	5.61	125	-19.9	-19.9	+18.63	+1,956.6	+32.4
France	22.1	+10	9.4	256.48	-54.57	+13.64	+254.73	+5,638.5	+20.8
Germany	2.7	+4	9.09	285.13	-54.57	+13.64	+117.32	+315	+1
Portugal	4.3	+12.5	5.51	278.31	-47.75	-47.75	+143.95	+613.6	+2.9
Czech Republic	5	+10	5.75	294.68	-47.75	-23.19	+146.25	+713.2	+2.9
Slovakia	0.9	+12.3	4.28	285.13	-47.75	-47.75	+102.35	+97.1	+0.5
Poland	0.3	+12.5	5.28	259.21	-47.75	-47.75	+123.33	+40	+0.2
Romania	0.3	+7.1	3.50	315.14	-43.66	-43.66	+34.66	+12	+0.1

Note. Impact on costs net of cost of technology = cost savings from reductions in pesticide costs, labor use, fuel use, etc., from which the additional cost (premium) of the technology has been deducted. For example (above), US cost savings from reduced expenditure on insecticides, etc. = +$15.88/ha, from which cost of technology (-$17.3/ha) is deducted to leave a net impact of costs of -$1.42.

There are no Canadian-specific studies available, so we have applied US study findings to the Canadian context (since it is the nearest country for which relevant data is available).

Table A2. GM IR corn (targeting corn rootworm), 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	8,417.6	+5	9.25	135.4	-35	+2.47	+65.10	+547,991	+3,893.2
Canada	39.3	+5	8.29	165.44	-35	+2.47	+71.04	+2,788.7	+16.3

Note. There are no Canadian-specific studies available, hence application of US study findings to the Canadian context (since it is the nearest country for which relevant data is available).

Table A3. GM IR cotton, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/ tonnes)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	2,585.2	+10	0.93	1,202	-46.95	-5.77	+106.02	+274,078	+240.4
China	3,800	+10	1.18	807.4	-48.07	+152.48	+248.08	+942,695	+449.9
South Africa	9.9	+24	0.692	1,172.0	-49.43	-31.23	+163.42	+1,617.8	+1.6
Australia	55.3	0	1.91	1,458	-251.3	+212.0	+212.09	+11,734.3	0
Mexico	60.0	+9.28	1.18	1088.7	-70.41	+20.49	+139.71	+8,382.1	+6.6
Argentina	162.3	+30	0.418	1,455	-37.85	-21.17	+161.31	+26,180.8	+20.3
India	5,868	+50	0.43	1,536.9	-55.29	-8.86	+321.57	+1,886,986	+1,261.6
Colombia	20.0	+9.28	0.95	1,900	-70.41	+20.49	+187.99	+3,749.8	+1.8
Brazil	358	+6.23	1.32	1,316.6	-43.94	+71.21	+135.54	+48,524	+29.4

Table A4. GM HT soybeans, 2007 (excluding second crop soybeans—see separate table).

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonnes)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	23,433.5	0	2.77	331	-24.71	+57.96	+57.96	+1,358,206.4	0
Canada	688	0	2.3	395	-37.47	+24.52	+24.52	+16,871.2	0
Argentina	16,419.5	0	2.83	221.7	-2.5	+26.11	+29.23	+480,012.1	0
Brazil	13,562.5	0	2.85	282.4	-18.77	+57.2	+61.2	+830,022.6	0
Paraguay	2,600	0	2.41	261.3	-9.64	+18.97	+22.11	+57,476.6	0
South Africa	144	0	1.12	356.6	-27.94	+5.01	+5.01	+722.1	0
Uruguay	443.5	0	2.19	256.1	-2.5	+26.11	+28.9	+12,819.2	0
Mexico	5	+9.1	1.48	360	-34.5	+120	+168.48	+842	+0.7
Romania	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Note. Quality premium for cleaner crops assumed at 0.5% of base price (price shown is inclusive of premium) in South American countries.

Romania—n/a = not applicable, as no longer permitted to plant GM HT soybeans on entry into the EU.

Table A5. GM HT corn, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	19,697.3	0%	9.48	135	-24.71	+19.89	+19.89	+391,779.1	0
Canada	751	0%	8.51	165.44	-31.8	+13.01	+13.01	+9,771.3	0
Argentina	369	+3% corn belt +22% marginal regions	7.68 corn belt 4.31 marginal areas	113	-19.9	0	+26.1 corn belt +107.43 marginal regions	+27,637.1	+244.1
South Africa	453	0%	4.29	304.47	-17.19	+6.02	+6.02	+2,725.8	0
Philippines	191.3	+15	2.52	215.12	-26.69	-26.69	+54.47	+10,419.2	+72.2

Note. Where no positive yield effect due to this technology is applied, the base yields shown are the indicative average yields for the crops and differ (are higher) than those used for the GM IR base yield analysis, which have been adjusted downwards to reflect the impact of the yield enhancing technology (see below).

Argentina: corn belt assumed to account for 70% of trait plantings and marginal regions to the balance.

Table A6. GM HT cotton, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	3,067.1	0	0.985	1,202	-70.35	+5.2	+5.2	+15,949	0
South Africa	9.7	0	0.8	1,172	-23.6	-22.9	-0.72	-7	0
Australia	50.5	0	1.91	1,458	-42.71	+7.54	+7.54	+380.4	0
Argentina	124	Farm saved seed area 0% Certified seed area +17.4%	0.453	1,455	-39.86 certified seed -8 farm saved seed	-17.67 certified seed +14.19 farm saved seed	+99.57 certified seed +14.19 farm saved seed	-3,876.5	+2.0
Mexico	50	+3.6	1.208	1,089	-66.4	+39.67	+87.02	+4,350.8	+2.2

Note. Where no positive yield effect due to this technology is applied, the base yields shown are the indicative average yields for the crops and differ (are higher) than those used for the GM IR base yield analysis, which have been adjusted downwards to reflect the impact of the yield enhancing technology (see below).

Argentina: 20% of area assumed to use certified seed with 80% farm-saved seed.

Table A7. GM HT canola, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonnes)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US glyphosate tolerant	271.9	+4	1.65	359.36	-12.36	+27.73	+51.45	+13,990.1	+5.2
US glufosinate tolerant	182.9	+10	1.65	359.36	-12.36	+22.28	+81.57	+14,918.4	+8.7
Canada glyphosate tolerant	2,840.9	+4	1.41	508.27	-34.01	+6.82	+35.49	+100,823.3	+160.2
Canada glufosinate tolerant	2,588.4	+10	1.41	508.27	0	+11.72	+83.38	+215,830.1	+365.0

Note. Baseline (conventional) comparison in Canada with HT (non GM) 'Clearfield' varieties.

Table A8. GM virus-resistant crops.

Country	Area of trait (ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US papaya	778	+15	22.86	864.36	-148	-148	+2,816.1	+2,190	+2.7
US squash	3002	+100	31.4	566.90	-398	-398	+17,402.9	+52,252.3	+94.3

Second Soybean Crop Benefits: Argentina

An additional farm income benefit that many Argentine soybean growers have derived comes from the additional scope for second cropping of soybeans. This has arisen because of the simplicity, ease, and weed management flexibility provided by the (GM) technology which has been an important factor facilitating the use of no- and reduced-tillage production systems. In turn, the adoption of low/no-tillage production systems has reduced the time required for harvesting and drilling subsequent crops and, hence, has enabled many Argentine farmers to cultivate two crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no- or low-tillage methods has increased from 34% in 1996 to 90% by 2005. Also, 30% of the total Argentine soybean crop was second crop in 2007, compared to 8% in 1996. Based on the additional gross margin income derived from second crop soybeans (see below), this has contributed a further boost to national soybean farm income of $1.1 billion in 2007 and $4.4 billion cumulatively since 1996.

Base Yields Used Where GM Technology Delivers a Positive Yield Gain

In order to avoid over-stating the positive yield effect of GM technology (where studies have identified such an impact) when applied at a national level, average (national level) yields used have been adjusted downwards (see example in Table A10). Production levels based on these adjusted levels were then cross checked with total production values based on reported average yields across the total crop.

Table A9. Farm-level income impact of using GM HT soybeans in Argentina, 1996-2007 (2): Second crop soybeans.

Year	Second crop area (million ha)	Average gross margin/ha for second crop soybeans ($/ha)	Increase in income linked to GM HT system (million $)
1996	0.45	128.78	Negligible
1997	0.65	127.20	25.4
1998	0.8	125.24	43.8
1999	1.4	122.76	116.6
2000	1.6	125.38	144.2
2001	2.4	124.00	272.8
2002	2.7	143.32	372.6
2003	2.8	151.33	416.1
2004	3.0	226.04	678.1
2005	2.3	228.99	526.7
2006	3.2	218.40	698.9
2007	4.94	229.36	1,133.6

Note. Crop areas and gross margin data based on data supplied by Grupo CEO (no data available before 2000, hence 2001 data applied to earlier years but adjusted, based on GDP deflator rates).

The second cropping benefits are based on the gross margin derived from second crop soybeans multiplied by the total area of second crop soybeans (less an assumed area of second crop soybeans that equals the second crop area in 1996—this was discontinued from 2004 because of the importance farmers attach to the GM HT system in facilitating them remaining in no-tillage production systems).

Table A10. Example: GM IR cotton (2007).

Country	Average yield across all forms of production (t/ha)	Total cotton area ('000 ha)	Total production ('000 tonnes)	GM IR area ('000 ha)	Conventional area ('000 ha)	Assumed yield effect of GM IR technology	Adjusted base yield for conventional cotton (t/ha)	GM IR production ('000 tonnes)	Conventional production ('000 tonnes)
United States	0.985	4,381.6	4,315.9	2,585.2	1,796.5	+10%	0.93	2,644.7	1,670.7
China	1.257	6,200.0	7,793.4	3,800.0	2,400.0	+10%	1.184	4,949.1	2,841.6

Note. Figures subject to rounding.

Appendix 2: Impacts, Assumptions, Rationale, and Sources for All Trait/Country Combinations

Table 1. IR corn (resistant to corn-boring pests).

Country	Yield impact assump. used	Rationale	Yield references	Sensitivity analysis applied to yield assump.	Cost of technology data/ assump.	Cost savings (excluding impact of seed premium) assump.	Cost references
GM IR corn resistant to corn boring pests							
US & Canada	+5% all years	Broad average of impact identified from several studies/ papers	Carpenter and Gianessi (2002) found yield impacts of +9.4% in 1997, +3% in 1998, +2.5% in 1999 Marra et al. (2002) average impact of +5.04% 1997-2000 based a review of five studies, James (2003) average impact of +5.2% 1996-2002, Sankula and Blumenthal (2003, 2006) range of +3.1% to +9.9% Canada—no studies identified —as US—impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007).	+3% to +9%	1996 & 1997: $25 1998 & 1999: $20 2000-2004: $22 2005 & onwards: $17	All years to 2004: $15.50 2005 onwards: $15.90	The same reference sources as yield were used. Industry sources also confirmed costs of technology and estimated cost-saving values for Canada.
Argentina	+9% all years to 2004 +5.5% 2005 onwards	Average of reported impacts in first seven years, later revised downwards for more recent years to reflect professional opinion	James (2003) cites two unpublished industry survey reports; one for 1996-1999 showing an average yield gain of +10% and one for 2000-2003 showing a yield gain of +8%. Trigo, Chudnovsky, Cap, and Lopez (2002), Trigo and Cap (2006) +10%, Trigo (personal communication, 2007, 2008) estimates average yield impact since 2005 to be lower at between +5% and +6%.	+5% all years to +9% all years	Same as US to 2005 then 60 Pesos 2006 onwards	None, as maize crops not traditionally treated with insecticides for corn boring pest damage	Cost of technology drawn from Trigo et al. (2002) and Trigo and Cap (2006), i.e., costed/priced at same level as US (Trigo, personal communication, 2007, 2008).
Philippines	+24.6% all years	Average of three studies used all years	Gonsalves (2005) found average yield impact of +23% dry season crops and +20% wet season crops; Yorobe (2004) +38% dry season crops and +35% wet season crops; Ramon (2005) found +15.3% dry season crops and +13.3% wet season crops.	All years +14% to +34%	All years: 1,673 Pesos	All years: 651 Pesos	Based on Gonsalves (2005)—the only source to break down these costs. For 2006 and 2007, this level of cost and average cost savings were confirmed by industry sources.
South Africa	2000-2001: +11% 2002: +32% 2003: +16% 2004: +5% 2005 onwards: +15%	Reported average impacts used for years available (2000-2004), 2005 onwards based on average of other years.	Gouse, Pray, Kirsten, and Schimmelpfenning (2005), Gouse, Piesse, and Thirtle (2006), and Gouse, Pray, Schimmelpfenning, and Kirsten (2006) reported yield impacts as shown (range of +11% to +32%).	+5% to +32% all years	(In Rand) 2000 & 2001: 84 2002: 90 2004 & 2005: 94 2006 and onwards: 113	All years 97 Rand	Based on the same papers as used for yield, plus confirmation in 2006 and 2007 that these are representative values from industry sources.

Spain	1998-2004: +6.3% 2005 onwards: +10%	Impact based on author's own detailed, representative analysis for period 1998-2002 then updated to reflect improved technology based on industry analysis.	Brookes (2003) identified an average of +6.3% using the Bt 176 trait mainly used in the period 1998-2004 (range +1% to +40% for the period 1998-2002). From 2005, 10% used based on Brookes (2008), which derived from industry (unpublish-ed sources) commercial-scale trials and monitoring of impact of the newer, dominant trait Mon 810 in the period 2003-2007. Gomez-Barbero and Rodriguez-Cerezo (2006) reported an average impact of +5% for Bt 176 used in 2002-2004.	+3% to +15% all years	(In Euros) 1998 & 1999: 30 2000: 28 2001-2005: 18.5 2006 and onwards: 35	42 Euros all years	Based on Brookes (2003), the only source to break down these costs. The more recent cost of technology costs derive from industry sources (reflecting the use of Mon 810 technology). Industry sources also confirm value for insecticide cost savings as being representative.
Other EU	France: +10% Germany: +4% Portugal: +12.5% Czech Rep.: +10% Slovakia: +12.3% Poland: +12.5% Romania: +7.1%	Impacts based on average of available impact data in each country.	Based on Brookes (2008), which drew on a number of sources. For France, four sources with average yield impacts of +5% to +17%; for Germany the sole source had average annual impacts of +3.5% and +9.5% over a two year period; for Czech Republic, three studies identified average impacts in 2005 of an average of 10% and a range of +5% to +20%; for Portugal, commercial trial and plot monitoring reported +12% in 2005 and between +8% and +17% in 2006; in Slovakia based on trials for 2003-2007 and 2006/07 plantings with yield gains averaging between +10% and +14.7%; in Poland based on variety trial tests 2005 and commercial trials 2006 which had a range of +2% to +26%; Romania based on estimated impact by industry sources for the 2007 year.	Not applied in context of total study due to very small scale of production (i.e., would produce an insignificant impact range in the context of the whole study).	France and Germany, 40 Euros Portugal, Czech and Slovak Republics, and Poland, 35 Euros Romania, 32 Euros	France and Germany, 50 Euros; Portugal, Slovakia, Poland and Romania, 0; Czech Republic, 18 Euros	Data derived from the same sources referred to for yield.
Uruguay	Same as Argentina	Same as Argentina	No country-specific studies identified, so impact analysis from nearest country of relevance (Argentina) applied.	Same as Argentina: +5% to +9%	Same as Argentina	Same as Argentina	Same as Argentina

GM IR corn (resistant to corn rootworm)								
US & Canada	+5% all years	Based on the impact used by the references cited.	Sankula and Blumenthal (2003, 2006) used +5% in analysis, citing this as conservative, themselves having cited impacts of +12%-+19% in 2005 in Iowa, +26% in Illinois in 2005, and +4%-+8% in Illinois in 2004. Johnson and Strom (2007) used the same basis as Sankula and Blumenthal. Rice (2004) range of +1.4% to +4.5% (based on trials) Canada—no studies identified—as US—impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007).	+3% to +9%	2003 & 2004: $42 2005 onwards: $35	2003: $33 2004 onwards: $37	Data derived from Sankula and Blumenthal (2006) and Johnson and Strom (2007). Canada—no studies identified — as US—impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007).
GM HT cotton								
US	0%	Not relevant	Not relevant	Not relevant	$12.85 1996-2000 $21.32 2001-2003 $34.55 2004 $68.22 2005 $70.35 2006 onwards	$34.12 1996-2000 $66.59 2001-2003 $83.35 2004 $71.12 2005 $75.55 2006 onwards	Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)—these are the only available studies breaking down impact into disaggregated parts.	
Australia	0%	Not relevant	Not relevant	Not relevant	Aus $50 all years	Aus $60 all years	Doyle et al. (2003) Monsanto Australia (personal communication, 2005, 2007, 2008)	
South Africa	0%	Not relevant	Not relevant	Not relevant	133 Rand 2001-2004 101 Rand 2005 165 Rand 2006 onwards	160 Rand all years	No studies identified—based on Monsanto South Africa (personal communication, 2005, 2007, 2008)	
Argentina	0% on area using farm saved seed, +17.4% on area using certified seed	Based on only available data—company monitoring of commercial plots.	No studies identified—based on personal communic-ations with Grupo CEO & Monsanto Argentina (2007, 2008).	+10% to +20% on certified seed area	122 Pesos all years	68 Pesos all years	No studies identified—based on personal communications with Grupo CEO and Monsanto Argentina (2007, 2008).	
Mexico	+3.6%	Based on only available data—company monitoring of commercial plots.	Same as source for cost data	0% to +5% all years	All years: 720 Pesos	All years: 1,150 Pesos	No studies identified—based on personal communications with Monsanto Mexico (2007).	

			IR cotton				
US	1996-2002: +9% 2003 & 2004: +11% 2005 onwards: +10%	Based on the (conserv-ative) impact used by the references cited	Sankula and Blumenthal (2003, 2006) drew on earlier work from Carpenter and Gianessi (2002) in which they estimated the average yield benefit in the 1996-2000 period was +9%. Marra et al. (2002) examined the findings of over 40 state-specific studies covering the period 1996 up to 2000, the approximate average yield impact was +11%. The lower of these two values was used for the period to 2002. The higher values applied from 2003 reflect values used by Sankula and Blumenthal (2006) and Johnson and Strom (2007) that take into account the increasing use of Bollgard II technology, and draws on work by Mullins and Hudson (2004) that identified a yield gain of +12% relative to conventional cotton. The values applied 2005 onwards were adjusted downwards to reflect the fact that some of the GM IR cotton area has still been planted to Bollgard I.	+5% to +15%	1996-2002: $58.27 2003 & 2004: $68.32 2005 onwards: $49.60	1996-2002: $63.26 2003-2005: $74.10 2006 onwards: $41.18	Data derived from the same sources referred to for yield.
China	1997-2001: +8% 2002 onwards: +10%	Average of studies used to 2001. Increase to 10% on basis of industry assess-ments of impact and reporting of unpublished work by Schuchan.	Pray, Huang, Hu, and Rozelle (2002) surveyed farm level impact for the years 1999-2001 and identified yield impacts of +5.8% in 1999, +8% in 2000, and +10.9% in 2001 Monsanto China (personal communication, 2007, 2008)	+6% to +12%	All years to 2005: $46.30 2006 onwards: 366 Yuan	2000: $261 2001: $438 average of these used all other years to 2004 2005 onwards: 1,530 Yuan	Data derived from the same sources referred to for yield.
Australia	None	Studies have usually identified no significant average yield gain.	Fitt (2001) Doyle (2005) James (2002) Commonwealth Scientific and Industrial Research Organisation (CSIRO, 2005)	None applied	(In Australian dollars) 1996 & 1997: $245 1998: $155 1999: $138 2000-2001: $155 2002: $167 2003: $190 2004: $250 2005 onwards: $300	1996: $151 1997: $157 1998: $188 1999: $172 2000-2002: $267 2003: $598 2004: $509 2005 onwards: $553	Data derived from the same sources referred to for yield (Fitt, 2001) covering earlier years of adoption, then CSIRO for later years. For 2006 and 2007 cost of technology values confirmed by personal communication from Monsanto Australia.

Argentina	+30% all years	More conservative of the two pieces of research used	Qaim and De Janvry (2002, 2005) analysis based on farm level analysis in 1999/00 and 2000/01 +35% yield gain, Trigo and Cap (2006) used an average gain of +30% based on work by Elena (2001).	+25% to +35%	All years to 2004: $86 2005 onwards: 116 Pesos	51 Pesos all years	Data derived from the same sources referred to for yield. Cost of technology in 2006 and 2007 also confirmed from industry sources.
South Africa	+24% all years	Lower end of estimates applied	Ismael et al. (2002) identified yield gain of +24% for the years 1998/99 & 1999/2000. Kirsten, Gouse, and Jenkins (2002) for 2000/01 season found a range of +14% (dry crops/large farms) to +49% (small farmers). James (2002) also cited a range of impact between +27% and +48% during the years 1999-2001.	+15% to +40%	All years to 2005: 149 Rand 2006 onwards: 345 Rand	127 Rand all years	Data derived from the same sources referred to for yield. Values for cost of technology and cost of insecticide cost savings also provided/ confirmed from industry sources.
Mexico	1996: +37% 1997: +3% 1998: +20% 1999: +27% 2000: +17% 2001: +9% 2002: +6.7% 2003: +6.4% 2004: +7.6% 2005: +9.25% 2006: +9% 2007: +9.28	Recorded yield impact data used as available for almost all years	The yield impact data for 1997 and 1998 is drawn from the findings of farm level survey work by Traxler et al. (2001). For all other years the data is based on the commercial crop monitoring reports required to be submitted to the Mexican government (Monsanto Mexico, 2005, 2007). As data from this source was not available for 2007, the yield applied in 2007 is the average for the period 2000-2006.	None applied as almost all years are crop-specific estimates	All years to 2005: 540 Pesos 2006 onwards: 760 Pesos	1996 & 1999 onwards: 985 Pesos 1997: $121 1998: $94	Data derived from the same sources referred to for yield
India	2002: +45% 2003: +63% 2004: +54% 2005: +64% 2006 & 2007: +50%	Recorded yield impact used for almost all years	Yield impact data 2002 and 2003 is drawn from Bennett et al. (2004), for 2004 the average of 2002 and 2003 was used. 2005 and 2006 are derived from IMRB (2006, 2007). 2007 impact data based on lower end of range of impacts identified in previous three years (2007 being a year of similar pest pressure to 2006—lower than average).	All years 45% to 65%	(in Rupees) 2002: 2,636 2003: 2,512 2004: 2,521 2005: $2,307 2006 & 2007: 2,211	(in Rupees) 2002: 2,032 2003: 1,767 2004: 1,900 2005: 1,362 2006: 2,308 2007: 1,857	Data derived from the same sources referred to for yield. 2007 cost of technology confirmed from industry sources and cost savings for 2007 taken as average of past three years
Brazil	+6.23%		The only data source identified (unpublished farm survey data—Monsanto Brazil, 2008) has been used covering the 2006 season. This has also been used for 2007.	All years: +4% to +8%	2006 onwards: $40	141 Real	Data derived from the same source referred to for yield.

GM HT soybeans							
US	0%	Not relevant	Not relevant	Not relevant	1996-2002: $14.82 2003: $17.30 2004: $19.77 2005 onwards: $24.71	1996-97: $25.20 1998-2002: $33.90 2003: $78.50 2004: $60.10 2005: $69.40 2006 onwards: $81.70	Marra, Pardey, and Alston (2002) Gianessi and Carpenter (1999) Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)
Canada	0%	Not relevant	Not relevant	Not relevant	(Canadian $) 1997-2002: $32 2003: $48 2004 & 2005: $45 2006 onwards: $41	Range of Can $66-89 1997-2007 converted to US $ at prevailing exchange rate	George Morris Centre (2004)
Argentina	0% but second crop benefits	Not relevant except 2nd crop—see separate table	Not relevant	Not relevant	$3-$4 all years to 2001 $1.20 2002-2005 (reflecting all use of farm saved seed) $2.50 2006 onwards (Monsanto royalty rate)	$24-$30: varies each year according to exchange rate	Qaim and Traxler (2002, 2005), Trigo and Cap (2006).
Brazil	0%	Not relevant	Not relevant	Not relevant	Same as Argentina to 2002 (illegal plantings) 2003: $9 2004: $15 2005: $16 2006: $19.80 2007: $18.80	$88 in 2004 applied to all other years at prevailing exchange rate	Data from the Parana Department of Agriculture (2004). Also agreed royalty rates from 2004.
Paraguay	0% but second crop benefits	Not relevant except 2nd crop	Not relevant	Not relevant	Same as Argentina to 2004 2005: $4.86 2006: $3.09 2007: $9.64	Same as Argentina	Same as Argentina: no country-specific analysis identified. Impacts confirmed from industry sources (personal communication, 2006, 2008).
South Africa	0%	Not relevant	Not relevant	Not relevant	All years to 2005: 170 Rand 2006 onwards: 195 Rand	230 Rand each year converted to US $ at prevailing exchange rate	No studies identified—based on Monsanto South Africa (personal communication, 2005, 2007, 2008).
Uruguay	0%	Not relevant	Not relevant	Not relevant	Same as Argentina	Same as Argentina	Same as Argentina: no country-specific analysis identified. Impacts confirmed from industry sources (personal communication, 2006, 2008).

Mexico	+9.1%	Recorded yield impact from studies	From Monsanto (2007) unpublished study—the only identified data	None applied—small scale plantings	$34.50 all years	$154.50	No studies identified based on Monsanto (2007) and updated by personal communication (2008).
Romania	+31%	Based on only available study covering 1999-2003 (note not grown in 2007).	For previous year—based on Brookes (2005)—the only published source identified	+20% to +40%	1999-2000: $160 2001: $148 2002: $135 2003 & 2004: $130 2005: $121 2006: $100 Not permitted for use in EU 2007 All years includes 4 liters of herbicide	1999-2006: $150-$192 depending on Euro to $ exchange rate 2007 not applicable—trait not permitted for growing in EU	Brookes (2005)
GM VR crops US								
Papaya	Between +15% and +50% 1999-2007—relative to base yield of 22.86 t/ha	Based on average yield in three years before first use.	Draws on only published source disaggregating to this aspect of impact.	+15% all years to +50% all years	$0 1999 to 2003 $42 2004 $148 2005 onwards	None—no effective conventional method of protection.	Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)
Squash	+100% on area planted	Assumes virus otherwise destroys crop on planted area.	Draws on only published source disaggregating to this aspect of impact.	+50% all years	$398 all years	None—no effective conventional method of treatment.	Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)

				GM HT corn			
US	0%	Not relevant	Not relevant	Not relevant	$14.80 all years to 2004 $17.30 2005 $24.71 2006 onwards	$39.90 all years to 2003 $40.55 2004 $40.75 2005 $44.60 2006 onwards	Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)—these are the only available studies breaking down impact into disaggregated parts.
Canada	0%	Not relevant	Not relevant	Not relevant	Can $27 1999-2005 Can $35 2006 onwards	Can $48.75 all years	No studies identified—based on personal communications with industry sources, including Monsanto Canada.
Argentina	+3% corn belt +22% marginal areas	Based on only available analysis—Corn Belt = 70% of plantings, marginal areas 30%—industry analysis (note no significant plantings until 2006)	No studies identified—based on personal communications with industry sources in 2007 and 2008 Monsanto Argentina and Grupo CEO (personal communication, 2007, 2008).	+1% to +5% corn belt, +15% to +30% marginal areas	61 Pesos all years	61 Pesos all years	No studies identified—based on Monsanto Argentina and Grupo CEO (personal communication, 2007, 2008).
South Africa	0%	Not relevant	Not relevant	Not relevant	80 Rand 2003-2005 120 Rand 2006 onwards	162 Rand all years	No studies identified—based on Monsanto South Africa (personal communication, 2005, 2007, 2008).
Philippines	+15%	Based on only available analysis—industry analysis		+10% to +20% all years	1,232 Pesos all years	Not known so conservative assumption of zero used	No studies identified—based on Monsanto Philippines (personal communication, 2007, 2008).

			GM HT canola				
US	+6% all years to 2004. Post 2004, based on Canada—see below	Based on the only identified impact analysis—post 2004 based on Canadian impacts as same alternative (conventional HT) technology to Canada available.	Same as source for cost data	All years: +3% to +9%	**Glyphosate tolerant** 1999-2001: $29.50 2002-2004: $33 2005 onwards: $12 **Glufosinate tolerant** All years for to 2004: $17.30 From 2005: $12	**Glyphosate tolerant** 1999-2001: $60.75 2002 & 2003: $67 2004: $69 2005: $49 2006 onwards: $40 **Glufosinate tolerant** All years to 2003: $44.89 2004: $44 2005: $40 2006 onwards: $435	Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007) These are the only studies identified that examine GM HT canola in the US.
Canada	+10.7% all years to 2004. After 2004, based on differences between average annual variety trial results for Clearfields (non-GM HT varieties) and GM alternatives. GM alternatives differentiated into glyphosate tolerant and glufosinate tolerant. This resulted in—for GM glyphosate tolerant varieties—no yield difference for 2004 and 2005 and +4% for 2006 and 2007. For GM glufosinate tolerant varieties, the yield differences were +12% in 2004, +19% in 2005, and +10% for 2006 and 2007.		Same as source for cost data	+4% to +12% all years	Can $44.63 all years to 2003 2004 onwards based on difference seed premium and technology fee relative to Clearfields HT canola; $0 for GM glufosinate tolerance and Can $37 for glyphosate tolerance	(In Canadian $) **Glyphosate tolerant** $39 all years to 2003 2004 onwards: $40 **Glufosinate tolerant** All years to 2003: $39 2004 onwards: $10	Based on Canola Council of Canada (2001) to 2003, then adjusted to reflect main current non GM (HT) alternative of 'Clearfields'—data derived from personal communicatio ns with the Canola Council of Canada (2008) and Gusta et al. (2008).

Readers should note that the assumptions are drawn from the references cited, supplemented and updated by industry sources (where the authors have not been able to identify specific studies). This has been particularly of relevance for some of the HT traits more recently adopted in several developing countries. Accordingly, the authors are grateful to industry sources who have provided information on impact, notably on cost of the technology and impact on costs of crop protection. While this information is not derived from detailed studies, the authors are confident that it is reasonably representative of average impacts; in fact, in a number of cases, information provided from industry sources via personal communications has suggested levels of average impact that are lower than those identified in independent studies. Where this has occurred, the more conservative (industry source) data has been used.

GLOBAL IMPACT OF BIOTECH CROPS: SOCIO-ECONOMIC & ENVIRONMENTAL EFFECTS 1996–2007

Graham Brookes & Peter Barfoot, PG Economics Ltd, Dorchester, UK outline the benefits that have been found with the growing of GM crops globally
www.pgeconomics.co.uk

Keywords: yield, cost, income, environmental impact quotient, carbon sequestration, GM crops

Introduction

This paper summarises the findings of research into the global socio-economic and environmental impact of biotech crops in the twelve years since they were first commercially planted on a significant area in 1996. Since then the global area using this technology has grown rapidly to in excess of 100 million hectares, highlighting the popularity of the technology amongst adopting farmers. In contrast, EU farmers have had little opportunity to adopt this technology with only one trait (insect resistant maize) approved for planting and the EU accounting for less than 0.5% of the global biotech crop in 2007. The paper focuses on the farm level economic effects, the production effects, the environmental impact resulting from changes in the use of insecticides and herbicides, and the contribution towards reducing greenhouse gas (GHG) emissions of biotech trait adoption. The research is based on, and draws from, an extensive literature review of impacts globally coupled with some collection and analysis of data, notably relating to pesticide usage. More detailed information and a full list of references can be found by referring to longer papers on this topic by the authors in the peer reviewed journal Agbioforum – www.agbioforum.org or directly from the PG Economics website (see above).

Farm Income Impacts

GM technology has had a significant positive impact on the income of farmers using the technology, derived from a combination of enhanced productivity and efficiency gains (Table 1). In 2007, the direct global farm income benefit from biotech crops was $10.1 billion. This is equivalent to having added 4.4% to the value of global production of the four main crops of soybeans, maize (corn), oilseed rape (canola) and cotton. Since 1996, farm incomes have increased by $44.1 billion. The largest gains in farm income have been in the soybean sector, largely from cost savings. The $3.9 billion additional income generated by GM herbicide tolerant (GM HT) soybeans in 2007 has been equivalent to adding the equivalent of 6.4% to the $60 billion value of this crop in 2007.

Substantial gains have also arisen in the cotton sector through a combination of higher yields and lower costs. In 2007, cotton farm income levels in the biotech adopting countries increased by $3.2 billion and from 1996 to 2007, the sector has benefited from an additional $12.6 billion. In 2007 alone, income gains from GM technology added 10.2% to the $27.5 billion value of total global cotton production, a substantial increase in value added terms for two new cotton seed technologies.

Significant increases to farm incomes have also been seen in the maize and canola sectors. The combination of GM insect resistant (GM IR) and GM HT technology in maize has boosted farm incomes by $7.2 billion since 1996. In the North American canola sector, an additional $1.4 billion has been generated.

Figure 1 summarises farm income impacts in key biotech adopting countries and this highlights the important farm income benefit arising from GM technology in South American countries, China and India and the US. It also illustrates the growing level of farm income benefits being obtained in South Africa, the Philippines and Mexico.

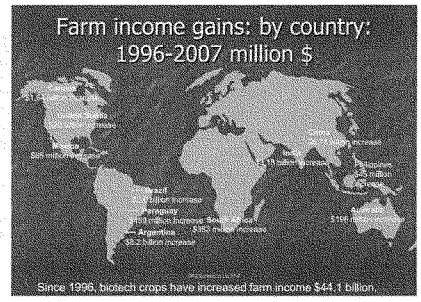


Figure 1

In terms of the division of the economic benefits obtained by farmers in less developed countries relative to farmers in developed countries, in 2007, 58% of the farm income benefits have been earned by less developed country farmers, wth the vast majority of these income gains coming from GM IR cotton and GM HT soybeans.[1] Over the twelve years,

[1] The authors acknowledge that the classification of different countries into less developed or developed country status affects the distribution of benefits between these two categories of country. The definition used in this paper is consistent with the definition used by James (2007)

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Table 1. Global farm income benefits from growing biotech crops 1996–2007: million US $

Trait	Increase in farm income 2007	Increase in farm income 1996–2007	Farm income benefit in 2007 as % of total value of production of these crops in biotech adopting countries	Farm income benefit in 2007 as % of total value of global production of crop
GM herbicide tolerant soybeans	3,935.5	21,814.1	7.2	6.4
GM herbicide tolerant maize	442.3	1,507.6	0.7	0.4
GM herbicide tolerant cotton	24.5	848.2	0.1	0.1
GM herbicide tolerant canola	345.6	1,438.6	7.65	1.4
GM insect resistant maize	2,075.3	5,673.6	3.2	1.9
GM insect resistant cotton	3,204.0	12,576.2	16.5	10.2
Others	54.4	208.8	Not applicable	Not applicable
Totals	**10,081.6**	**44,067.1**	**6.9**	**4.4**

Notes: All values are nominal. Others = Virus resistant papaya and squash. Totals for the value shares exclude 'other crops' (ie, relate to the 4 main crops of soybeans, maize, canola and cotton). Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality and key variable costs of production (eg, payment of seed premia, impact on crop protection expenditure)

Table 2. Cost of accessing GM technology (million $) relative to the total farm income benefits 2007

	Cost of technology: all farmers	Farm income gain: all farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology: less developed countries	Farm income gain: less developed countries	Total benefit of technology to farmers and seed supply chain: less developed countries
GM HT soybeans	930.8	3,935.5	4,866.3	326	2,560.5	2,886.5
GM IR maize	714.3	2,075.3	2,789.6	79.1	301.9	381
GM HT maize	530.8	442.3	973.1	20.2	40.8	61
GM IR cotton	670.4	3,204.0	3,874.4	535.1	2,918.1	3,353.2
GM HT cotton	226.4	24.5	250.9	8.5	8.2	16.7
GM HT canola	102.2	345.6	447.8	N/a	N/a	N/a
Total	**3,174.9**	**10,027.2**	**13,202.1**	**968.9**	**5,829.5**	**6,798.4**

N/a = not applicable. Cost of accessing technology based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents. Total farm income gain excludes $54.4 million associated with virus resistant crops in the US

1996-2007, the cumulative farm income gain derived by less developed country farmers was $22.1 billion (50.1% of the total).

Examining the cost farmers pay for accessing GM technology, Table 2 shows that across the four main biotech crops, the total cost in 2007 was equal to 24% of the total technology gains (inclusive of farm income gains plus cost of the technology payable to the seed supply chain[2]). For farmers in less developed countries the total cost was equal to 14% of total technology gains, whilst for farmers in developed countries the cost was 34% of the total technology gains. These differences are accounted for by factors such as weaker provision and enforcement of intellectual property rights in less developed countries and the higher average level of farm income gain on a per hectare basis derived by less developed country farmers.

Indirect (non pecuniary) Farm Level Impacts

As well as the more tangible and quantifiable impacts on farm profitability presented above, there are other important, more intangible (difficult to quantify) impacts of an economic nature that studies have identifed. The main ones are:

For herbicide tolerant crops the main benefits are:

- increased management flexibility and convenience that comes from a combination of the ease of use associated with broad-spectrum, post emergent herbicides like glyphosate and the wider window for spraying;
- reduced damage to crops by inputs. In a conventional crop, post-emergent weed control relies on herbicide applications before the weeds and crop are well established to achieve maximum efficacy. As a result, the crop may suffer 'knock-back' to its growth from the effects of the herbicide. In a GM HT crop, this problem is avoided because the crop is both tolerant to the herbicide and spraying can occur at a later stage when the crop is better able to withstand any possible "knock-back" effects;
- facilitation of the adoption of conservation or no tillage systems. This provides additional cost saving benefits such as reduced labour and fuel costs associated with ploughing, in addition to greater moisture retention and reductions in levels of soil erosion;
- improvements in levels of weed control. This has contributed to reduced harvesting costs – cleaner crops have resulted in reduced times for harvesting. It has also improved harvest quality and led to higher levels of quality price bonuses in some regions and years (eg, HT soybeans and HT canola in the early years of adoption respectively in Romania and Canada[3]);
- elimination of potential damage caused by soil-incorporated residual herbicides in follow-on crops;
- reduced need to apply herbicides in a follow-on crop because of the improved weed control.

For insect resistant crops the main benefits are:

- improved production risk management – the technology takes away much of the worry of significant pest damage occurring and is, therefore, highly valued;
- reduced management time. A 'convenience' benefit from having to devote less time to crop walking and applying insecticides;
- savings in energy use – mainly associated with less use of aerial spraying;
- savings in machinery use (for spraying and possibly reduced harvesting times[4]);
- better crop quality. There is a growing body of research evidence[5] relating to the superior quality of GM IR corn relative to conventional and organic corn from the perspective of having lower levels of mycotoxins;
- improved health and safety for farmers and farm workers, from reduced handling and use of pesticides, especially in less developed countries where many apply pesticides with little or no use of protective clothing and equipment;
- shorter growing season (eg, for some cotton growers in India) which allows some farmers to plant a second crop in the same season[6];
- benefits to the local environment from reduced spraying. For example, Some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.[7]

Since the early 2000s, a number of farmer-survey based studies in the US have attempted to quantify these non pecuniary benefits. These studies have usually employed contingent valuation techniques.[8] Drawing on this analysis, the estimated value for non pecuniary benefits derived from biotech crops in the US (1996-2007) is $5.11 billion, equal to 26% of the total cumulative (1996-2007) direct farm income. Similar benefits are likely likely to have accrued in other countries, but have not yet been quantified.

Production Effects on the Technology

Based on the yield assumptions used in the direct farm income benefit calcuations presented above and taking account of the second soybean crop facilitation in South

[2] The cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers

[3] See for example Brookes (2005) relating to Romania and the Canola Council (2001) relating to Canada cited in the full Brookes & Barfoot (2009) paper

[4] For example, when there is lower incidence of crops falling over slowing the speed of harvesting equipment – a notable benefit of GM IR technology in maize – see for example Brookes (2002) relating to Spain, cited in the full Brookes & Barfoot (2009) paper

[5] See Brookes (2008) relating to the adoption of Bt maize in Europe, cited in the full Brookes & Barfoot (2009)

[6] Notably maize in India – see for example, Manjunath T (2008) cited in the full Brookes & Barfoot (2009) paper

[7] Manjunath T (2008) cited in the full Brookes & Barfoot (2009) paper

[8] Survey based method of obtaining valuations of non market goods that aim to identify willingness to pay for specific goods (eg, environmental goods, peace of mind, etc) or willingness to pay to avoid something being lost

America (see below), biotech crops have made important contributions to global production of corn, cotton, canola and soybeans since 1996 (Table 3). The biotech IR traits, used in the corn and cotton sectors, have accounted for 99% of the additional corn production and almost all of the additional cotton production and since 1996 the average yield impact across the total area planted to these traits over the 12 year period has been +6.1% for corn traits and +13.4% for cotton traits.[9]

Table 3. Additional crop production arising from positive yield effects of biotech crops

	1996–2007 additional production (million tonnes)	2007 additional production (million tonnes)
Soybeans	67.80	14.46
Corn	62.42	15.08
Cotton	6.85	2.01
Canola	4.44	0.54

Although the primary impact of biotech HT technology has been to provide more cost effective (less expensive) and easier weed control versus improving yields from better weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless occurred, delivering higher yields in some countries. Specifically, HT soybeans in Romania improved the average yield by over 30% and biotech HT corn in Argentina and the Philippines delivered yield improvements of +9% and +15% respectively.[10]

Biotech HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle (eg, by not needing to plough). This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 67.5 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2006 (accounting for 99% of the total biotech-related additional soybean production).[11]

Impact on Pesticide Use and the Associated Environmental Impact

To examine the environmental impact of pesticide use with biotech crops, studies have analysed both active ingredient use and utilised the indicator known as the Environmental Impact Quotient (EIQ[12]) to assess the broader impact on the environment (plus impact on animal and human health). The EIQ distils the various environmental and health impacts of individual pesticides and agricultural practices in different production systems into a single 'field value per hectare' by drawing on all of the key toxicity and environmental exposure data related to individual products. It therefore provides a consistent and fairly comprehensive measure to compare the impact of crop protection practices in various production systems (be they GM, conventional or organic) on the environment and human health. Table 4 summarises the environmental impact over the last twelve years and shows that there have been important environmental gains associated with adoption of biotechnology. More specifically, the analysis presented in the full Brookes & Barfoot (2009) paper shows that:

- Since 1996, the quantity of herbicides and insecticides applied to the biotech crop area was reduced by 359 million kg of active ingredient (8.8% reduction). The overall environmental impact associated with their use on these crops was reduced by 17.2%;
- In absolute terms, the largest environmental gain has been associated with the adoption of GM HT soybeans, which reflects the large share of global soybean plantings accounted for by biotech varieties. The volume of herbicides used in biotech soybean crops decreased by 73 million kg (1996-2007), a 4.6% reduction, and, the overall environmental impact associated with herbicide use on these crops decreased by 20.9% (compared to the probably impact if this cropping area had been planted to conventional soybeans). However, it should be noted that in some countries, such as in South America, the adoption of GM HT soybeans coincided with increases in the volume of herbicides used relative to historic levels on a number of arable crops (both GM and conventional). This largely reflects the facilitating role of the GM HT technology in accelerating and maintaining the switch away from conventional tillage to no/low tillage production systems with their inherent other environmental benefits (notably reductions in greenhouse gas emissions and reduced soil erosion). Despite this net increase in the volume of herbicides used in some countries, the associated EIQ values still fell, as farmers switched to herbicides with a more environmentally benign profile;
- Major environmental gains have also been derived from the adoption of GM IR cotton. These gains were the largest of any crop on a per hectare basis. Since 1996, farmers have used 147.6 million kg less insecticide in GM IR cotton crops (a 23% reduction), and this has reduced the associated environmental impact of insecticide use on this crop area by 27.8%;
- Important environmental gains have also arisen in the maize and canola sectors. In maize, herbicide and insecticide use decreased by 92 million kg and the associated environmental impact on this crop area

[9] See the full Brookes & Barfoot (2009) paper for additional information
[10] See the full Brookes & Barfoot (2009) paper for additional information
[11] See the full Brookes & Barfoot (2009) paper for additional information
[12] Developed at Cornell University

Table 4. Impact of changes in the use of herbicides and insecticides from growing biotech crops globally 1996–2007

Trait	Change in volume of active ingredient used (million kg)	Change in field EIQ impact (in terms of million field EIQ/ha units)	% change in ai use on biotech crops	% change in environmental impact associated with herbicide & insecticide use on biotech crops
GM herbicide tolerant soybeans	–730.0	–6,283	–4.6	–20.9
GM herbicide tolerant maize	–81.8	–1,934	–6.0	–6.8
GM herbicide tolerant cotton	–37.0	–748	–15.1	–16.0
GM herbicide tolerant canola	–9.7	–443	–13.9	–25.8
GM insect resistant maize	–10.2	–528	–5.9	–6.0
GM insect resistant cotton	–147.6	–7,133	–23.0	–27.8
Totals	**–359.3**	**–17,069**	**–8.8**	**–17.2**

decreased, due to a combination of reduced insecticide use (5.9%) and a switch to more environmentally benign herbicides (6%). In canola, farmers reduced herbicide use by 9.7 million kg (a 13.9% reduction) and the associated environmental impact of herbicide use fell by 25.8% (due to a switch to more environmentally benign herbicides).

Fifty two per cent of the environmental benefits (1996-2007) associated with lower insecticide and herbicide use have been in less developed countries, the vast majority of which have been from the use of GM IR cotton and GM HT soybeans.

Impact on Greenhouse Gas (GHG) Emissions

Biotech crops contribute to lower levels of GHG emissions in two principle ways[13]:

- Reduced fuel use from less frequent herbicide or insecticide applications and a reduction in the energy use in soil cultivation. In 2007, this amounted to about 1,144 million kg of carbon dioxide savings (arising from reduced fuel use of 416 million litres). Over the period 1996 to 2007 the cumulative permanent carbon dioxide reduction is estimated at 7,090 million kg of carbon dioxide (arising from reduced fuel use of 2,578 million litres);
- Use of 'no-till' and 'reduced-till'[14] farming systems. These production systems have increased significantly with the adoption of GM HT crops because the technology has improved growers ability to control competing weeds, without the need to rely on soil cultivation and seed-bed preparation. As a result, tractor fuel use for tillage is reduced (see above), soil quality is enhanced and levels of soil erosion cut. In turn, more carbon remains in the soil and this leads to lower GHG emissions. As a result of the rapid adoption of no till/reduced tillage farming systems in North and South America, an extra 3,570 million kg of soil carbon is estimated to have been sequestered in 2007 (equivalent to 13,103 million tonnes of carbon dioxide that has not been released into the global atmosphere). Cumulatively the amount of carbon sequestered may be higher due to year-on-year benefits to soil quality.[15] However, with only an estimated 15%-25% of the crop area in continuous no-till systems it is currently not possible to estimate confidently cumulative soil sequestration gains.

[13] Additional details about how these values are calculated and associated references can be found in the full Brookes & Barfoot (2009) paper. Limited availability of space for this article means full details cannot provided here and therefore interested readers should consult the full report

[14] No-till farming means that the ground is not ploughed at all, while reduced tillage means that the ground is disturbed less than it would be with traditional tillage systems. For example, under a no-till farming system, soybean seeds are planted through the organic material that is left over from a previous crop such as corn, cotton or wheat

[15] The optimum conditions for soil sequestration are high biomass production of both surface residue and decaying roots that decompose in moist soils where aeration is not limiting

Placing these carbon sequestration benefits within the context of the carbon dioxide emissions from cars, Table 5 shows that:

- In 2007, the permanent carbon dioxide savings from reduced fuel use were the equivalent of removing nearly 495,000 cars from the road for a year;
- The additional probable soil carbon sequestration gains in 2007 were equivalent to removing nearly 5.823 million cars from the roads for a year;
- In total, the combined biotech crop-related carbon dioxide emission savings from reduced fuel use and additional soil carbon sequestration in 2007 were equal to the removal from the roads for a year of nearly 6.3 million cars, equivalent to about 24% of all registered cars in the UK;
- It is not possible to estimate confidently the soil carbon sequestration gains since 1996. If the entire biotech crop in reduced or no tillage agriculture during the last twelve years had remained in permanent reduced/no tillage then this would have resulted in a carbon dioxide saving of 83.18 million kg, equivalent to taking 36.97 million cars off the road for a year. This is, however a maximum possibility and the actual levels of carbon dioxide reduction are likely to be lower.

Table 5. Biotech crop environmental benefits from lower insecticide and herbicide use 1996–2007: developing versus developed countries

	Change in field EIQ impact (in terms of million field EIQ/ha units): developed countries	Change in field EIQ impact (in terms of million field EIQ/ha units): less developed countries
GM HT soybeans	–3,559	–2,724
GM IR maize	–516	–12
GM HT maize	–1,910	–23
GM IR cotton	–1,053	–6,080
GM HT cotton	–726	–22
GM HT canola	–444	Not applicable
Total	**–8,208**	**–8,862**

Concluding comments

Biotechnology has, to date, delivered several specific agronomic traits that have overcome a number of production constraints for many farmers, decreased pesticide spraying and signficantly boosted farm incomes. In addition, this has contributed to reducing the release of greenhouse gas emissions from agriculture. The technology has also made important contributions to increasing the yields of many farmers, reducing production risks, improving productivity and raising global production of key crops. This combination of economic and environmental benefit delivery is, therefore, already making a valuable contribution to improving the sustainability of global agriculture, with these benefits and improvements being greatest in less developed countries.

Table 6. Context of carbon sequestration impact 2007: car equivalent

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the permanent fuel savings ('000s)	Potential additional soil carbon sequestration savings (million kg of carbon dioxide	Average family car equivalents removed from the road for a year from the potential additional soil carbon sequestration ('000s)
US: GM HT soybeans	247	110	3,999	1,777
Argentina: GM HT soybeans	609	271	6,136	2,727
Other countries: GM HT soybeans	91	40	1,341	596
Canada: GM HT canola	131	58	1,627	723
Global GM IR cotton	37	16	0	0
Total	**1,115**	**495**	**13,103**	**5,823**

Notes: Assumption: an average family car produces 150 grams of carbon dioxide of km. A car does an average of 15,000km/year and therefore produces 2,250kg of carbon dioxide/year

Further Reading

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Graham Brookes is an agricultural economist and consultant who has, over the last twelve years, undertaken a number of research projects relating to the impact of agricultural biotechnology and written widely on the subject. This work includes annual updates of the global economic and environmental impact of GM crops since 1996, papers on co-existence of GM and non GM crops, the possible impact of GM crops in the a number of EU countries (eg, UK, Poland, Slovakia and Hungary), the actual impact of insect resistant maize in Spain and herbicide tolerant soybeans in Romania, GM crop market dynamics and GM rice crop developments to 2012, the impact of GMO labelling in Europe, the economic impact of GMO zero tolerance legislation and the cost to the UK economy of failure to embrace agricultural biotechnology.

Peter Barfoot is a specialist in biotechnology, having previously worked for the Agricultural Genetics Company (UK) and now runs the successful Bioportfolio.com website. He formed PG Economics with Graham in 1999 specifically to undertake research consultancy projects focusing on the impact of new technology in agriculture. He has co-authored several papers on the impact of biotechnology in agriculture (see above) with Graham Brookes.

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The Production and Price Impact of Biotech Corn, Canola, and Soybean Crops

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Biotech crops have now been grown commercially on a substantial global scale since 1996. This article examines the production effects of the technology and impacts on cereal and oilseed markets through the use of agricultural commodity models. It analyses the impacts on global production, consumption, trade, and prices in the soybean, canola, and corn sectors. The analysis suggests that world prices of corn, soybeans, and canola would probably be, respectively, 5.8%, 9.6%, and 3.8% higher, on average, than 2007 baseline levels if this technology was no longer available to farmers. Prices of key derivatives of soybeans (meal and oil) would also be between 5% and 9% higher, with rapeseed meal and oil prices being about 4% higher than baseline levels. World prices of related cereals and oilseeds would also be expected to be higher by 3% to 4%.

Key words: biotech crops, prices, yield, soybeans, corn, canola, partial-equilibrium model, price effects.

The effect of no longer using the current widely used biotech traits in the corn, soybean, and canola sectors would probably impact negatively on both the global supply and utilization of these crops, their derivatives and related markets for grain and oilseeds. The modeling suggests that average global yields would fall for corn, soybeans, and canola and despite some likely 'compensatory' additional plantings of these three crops, there would be a net fall in global production of the three crops of 14 million tonnes. Global trade and consumption of these crops/derivatives would also be expected to fall. The production and consumption of other grains such as wheat, barley, and sorghum and oilseeds—notably sunflower—would also be affected. Overall, net production of grains and oilseeds (and derivatives) would fall by 17.7 million tonnes, and global consumption would fall by 15.4 million tonnes. The cost of consumption would also increase by $20 billion (3.6%) relative to the total cost of consumption of the (higher) biotech-inclusive level of world consumption. The impacts identified in this analysis are, however, probably conservative, reflecting the limitations of the methodology used. In particular, the limited research conducted to date into the impact of the cost-reducing effect of biotechnology (notably in herbicide-tolerant [HT] soybeans) on prices suggests that the price effects identified in this article represent only part of the total price impact of the technology.

Introduction

Biotechnology crop traits have been grown on a widespread commercial global basis since 1996, and in 2008, the global cultivation area of biotech crops reached 125 million hectares, a 74-fold increase from the 1996 level. The number of countries adopting biotech crop cultivation has also increased from six in 1996 to 25 in 2008, with the United States leading the way in the utilization of biotechnology in crop production. The rapid growth of biotech crop hectares between 1996 and 2008 has made this the most rapidly adopted crop technology in agriculture over this period (James, 2008).

Currently, the biotech crop hectares are primarily utilized for soybeans, corn, cotton, and canola. The technology used thus far has been agronomic, cost-saving technology delivering herbicide tolerance in all four of these crops and insect resistance in the crops of corn and cotton. This technology has provided farmers with productivity improvements through a combination of yield improvement and cost reductions. As such, the technology is likely to have had an impact on the prices of soybeans, corn, cotton, and canola (and their derivatives) both in the countries where farmers have used biotech traits and in the global market.

Assessing the impact of the biotechnology applications on the prices of soybeans, corn, cotton, and canola (and their derivatives) is challenging since current and past prices reflect a multitude of factors—of which the introduction and adoption of new, cost-saving technologies is one. This means that disaggregating the effect of different variables on prices is far from easy. Previous

studies have contributed to the literature by evaluating the impacts of biotechnology application for field crops on national/regional economies and farmers' welfare (e.g., Anderson, Valenzuela, & Jackson, 2008; Martin & Hyde, 2001; Sobolevsky, Moschini, & Lapan, 2005). However, most of these studies primarily focused on a single crop, such as soybeans, corn, or cotton. Thus, the impact analysis of biotechnology adoption did not capture the responsiveness of the production of other crops. Furthermore, since the application of biotechnology usually occurs in various field crops, the joint impacts of biotechnology adoption on local and global agricultural markets need to be further explored.

Realizing the surging significance of biotechnology application in the US and global crop markets, this article summarizes the productivity impacts of biotech crops[1] (on production) and presents the findings of analysis that has sought to quantify the impact of the use of biotech traits on usage and the prices of corn, soybeans, and canola and their main derivatives.[2]

Methodology

The approach used to estimate the impacts of biotech crops on usage, trade, and prices of the three crops and their derivatives has been to draw on part of a broad modelling system of the world agricultural economy comprised of US and international multi-market, partial-equilibrium models of production, use, and trade in key agricultural commodities.[3] The models cover major temperate crops, sugar, ethanol and biodiesel, dairy, and livestock and meat products for all major producing and consuming countries and calibrated on most recently available data. Extensive market linkages exist in these models, reflecting derived demand for feed in livestock and dairy sectors, competition for land in production, and consumer substitution possibilities for close substitutes such as vegetable oils and meat types. The models capture the biological, technical, and economic relationships among key variables within a particular commodity and across commodities. They are based on historical data analysis, current academic research, and a reliance on accepted economic, agronomic, and biological relationships in agricultural production and markets. A link is made through prices and net trade equations between the US and international models. The models are used to establish 10-year commodity projections for a baseline and for policy analysis and are used extensively for the market outlook and policy analysis.

In general, for each commodity sector, the economic relationship that supply equals demand is maintained by determining a market-clearing price for the commodity. In countries where domestic prices are not solved endogenously, these prices are modelled as a function of the world price using a price transmission equation. Since the models for each sector can be linked, changes in one commodity sector will impact other sectors. For this particular study, the US Crops, International Grains, International Oilseed, International Sugar, and International Bio-fuels models were used.

In terms of the structure of the models, the following identity is satisfied for each country/region and the world.

$$\text{Beginning Stock} + \text{Production} + \text{Imports} = \text{Ending Stock} + \text{Consumption} + \text{Exports} \quad (1)$$

Production is divided into yield and area equations, while consumption is divided into feed and non-feed demand. The models include behavioral equations for area harvested, yield, crop production on the supply side, and per-capita consumption and ending stocks on the demand side. Equilibrium prices, quantities, and net trade are determined by equating excess supply and excess demand across countries and regions.

More specifically, in terms of acreage, harvested area is expressed as a function of own and competing crop prices in real terms as well as lagged harvested area and prices. Prices enter area functions either as part of real gross returns per unit of land (price multiplied by yield) or merely as prices, depending on the particular commodity model. The US model, because of extensive data availability, is divided into nine regions. The planted area for each crop within each region depends on expected net returns—which include real, variable production expenses per unit of land—for the crop and competing crops.

To satisfy the identity in Equation 1, two different methods are used. In most of the countries, domestic price is modelled as a function of the world price with a price transmission equation, and the identity is satisfied with one of the variables set as the residual. In other cases, prices are solved to satisfy the identity.

1. *Drawing primarily on work by one of the authors, Brookes and Barfoot (2008). A more detailed paper is also available on http://www.pgeconomics.co.uk/pdf/globalimpactstudyjune2008pgeconomics.pdf.*
2. *The impact of biotech traits in the cotton sector is not included in the analysis.*
3. *More details about the modelling structure are presented in Appendix A.*

Agricultural and trade policies in each country are included in the models to the extent that they affect the supply and demand decisions of the economic agents. The models assume that the existing agricultural and trade policy variables will remain unchanged in the outlook period. Macroeconomic variables, such as GDP, population, and exchange rates, are exogenous variables that drive the projections of the model. All models are calibrated on 2007/08 marketing year data for crops; 10-year annual projections for supply and utilization of commodities and prices for the US and the world are generated for the period between 2008 and 2017. Elasticity values for supply and demand responses are based on econometric analysis and on consensus estimates. Elasticity parameters estimates and policy variables are available at Iowa State University's Food and Agricultural Policy Research Institute (FAPRI) website.[4]

Data for commodity supply and utilization are obtained from the F.O. Lichts online database, the Food and Agriculture Organization (FAO) of the United Nations (FAOSTAT Online, 2006), the Production, Supply, and Distribution View (PS&D) of the US Department of Agriculture (USDA), the European Commission Directorate General for Energy and Transport, the ANFAVEA (2005), and UNICA (2006). Supply and utilization data include production, consumption, net trade, and stocks. The macroeconomic data are gathered from the International Monetary Fund and Global Insight.

The empirical analysis relies on these agricultural commodity models of the main regions of the world (e.g., North and South America, the EU-27, etc.) to estimate the impact on national, regional, and world markets and prices for cereals and oilseeds. These models have been developed to allow for forward-looking projections (over a 10-year period) to be made relating to production, use, trade, and prices of key commodities. The models are not directly able to estimate the impact of the technology on past prices (of corn, soybeans, and canola and their key derivatives). One advantage of these models is that it is possible to establish a baseline and then remove the impact of biotechnology on yields. This allows the isolation of the impact on prices and usage due to biotech crops and not due to other factors such as macroeconomic and weather variables. However, the models *do not* allow for estimating the impact on crop prices arising from changes to the cost base of crop production (a major impact of HT technology). Some (limited) economic analysis has been previously undertaken to estimate the impact of biotechnology-induced cost-of-production changes, notably on the global prices of soybeans. Moschini, Lapan, and Sobolevsky (2000) estimated that by 2000 the influence of biotech soybean technology on world prices of soybeans had been between -0.5% and -1%, and that as adoption levels increased this could be expected to increase up to -6% (if all global production was biotech). Qaim and Traxler (2002, 2005) estimated the impact of GM HT soybean technology adoption on global soybean prices to have been -1.9% by 2001. Based on this analysis, they estimated that by 2005 it was likely that the world price of soybeans may have been lower by between 2% and 6% than it might otherwise have been in the absence of biotechnology. This benefit will have been dissipated through the post-farm gate supply chain, with some of the gains having been passed onto consumers in the form of lower real prices. We, therefore, acknowledge the failure to include the potential impact of biotechnology on costs of production and prices as a limitation of the research, which potentially underestimates the impact of the technology on prices. In addition, the analysis uses 2007 as the baseline against which the analysis is run. This assumes that the level of biotech trait adoption in 2007 represents the 'counterfactual situation.' In doing so, it fails to take into account likely trends in biotech trait adoption post 2007 and hence, this additional weakness of the analysis probably contributes further to understating the price effect of biotechnology. Despite these methodological weaknesses, the approach used in this article provides a useful tool for assessing the impact of biotech traits on the prices of corn, canola, soybeans, and derivatives of these crops on global markets.

Yield and production change assumptions for the impact of biotech crops were used as bases for analysis in the models by projecting forward a 'what if' scenario in which the currently used biotech traits were no longer available. The yield and production change assumptions used were those identified in the published work of Brookes and Barfoot (2008).[5] For example, insect-resistant (IR) corn technology in the United States has delivered an average 5% improvement in corn yields. The Brookes and Barfoot analysis is itself based on a literature review of impacts of biotechnology traits globally

4. *http://www.fapri.iastate.edu/tools/*

5. *Also available at http://www.pgeconomics.co.uk. The specific yield impacts used derive from Appendix 2 of the AgBioForum article (2008).*

Table 1. Corn: Yield and production impact of IR traits, 1996-2006.

	Cumulative total corn area (ha)[a]	Cumulative trait area (ha)	% of crop to trait[b]	Average trait impact on yield %[c]	Average yield impact (tonnes/ha)	Additional production from trait (tonnes)
US corn-borer resistant	351,842,503	81,016,473	23%	+5.0%	+0.45	36,078,447
US corn-rootworm resistant	As above	6,596,520	1.9%	+5.0%	+0.45	3,130,130
Canada corn-borer resistant	13,269,070	4,239,214	31.9%	+5.0%	+0.38	1,628,075
Canada corn-rootworm resistant	As above	35,317	0.3%	+5.0%	+0.38	14,537
Argentina corn-borer resistant	23,951,406	10,024,000	41.9%	+7.6%	+0.49	4,862,787
Philippines corn-borer resistant	10,082,808	247,698	2.5%	+24.1%	+0.52	127,920
South Africa corn-borer resistant	21,909,720	2,392,000	10.9%	+14.5%	+0.43	1,034,735
Uruguay corn-borer resistant	184,000	100,000	54.3%	+6.1%	+0.31	30,559
Spain corn-borer resistant	4,013,343	303,656	7.6%	+7.6%	+0.72	218,132
Cumulative totals	**425,252,850**	**104,954,778**	**24.7**	**+5.7%**	**+0.45**	**47,125,322**
2006	**41,751,216**	**20,640,503**	**49%**	**+6.7%**	**+0.47**	**9,734,898**

[a] *For consistency purposes, the total areas presented refer only to the years in which the IR traits were used by farmers—from 1996 in the US and Canada, from 1998 in Spain and Argentina, from 2000 in South Africa, from 2003 in the Philippines, and from 2004 in Uruguay. Corn rootworm-resistant corn has also been available to US farmers from 2003 and to Canadian farmers from 2004.*

[b] *From year of first commercial planting to 2006.*

[c] *Average of impact over years of use, as used by Brookes and Barfoot (2008).*

since 1996, and details of the specific country and trait-specific studies used can be found in the references section of this article. To analyze the impact of this yield improvement, first a baseline is established (starting in 2008, and for the next 10 years covered by the model projections) with the trend growth rate of yield. Then a scenario is run where the yields were effectively lower than the baseline level (starting in 2008 and ending in 2017). The baseline represents the current status quo (technology used) and the scenario implies that the technology is no longer available. The difference between the baseline and scenario represents the impact of the technology (or more literally the impact of no longer using the technology).

The models effectively assume the decreases in average crop (e.g., corn) yield in the countries using GM technology as a 'shock' change to the various regional parts of the models. This then calculates revised yield values, changes in production and consumption, changes in stocks, changes in imports and exports, and changes in areas allocated to other crops. 'Knock-on' effects[6] on the price of each crop (corn, soybeans, and canola) plus effects on other crop (e.g., wheat, barley, sunflower) were also derived, both at a regional and a world level. Knock-on effects on derivatives of corn, soybeans, and canola are also derived.

Production and Yield Assumptions

The production and yield change assumptions used in this analysis derive from the work of Brookes and Barfoot (2008), which itself draws on numerous crop and country-level impact studies. The next section (*Production and Yield Impacts of Biotech Crops*) provides a summary of this data, and the assumptions used for the analysis are presented in the following section (*Conversion of Production and Yield Impacts into Useable Assumptions*).

6. *Indirect effects on the prices of derivatives as a result of changes in the price of the base commodities (e.g., a change in the price of soybeans affecting the price of soymeal). Also, the effect on prices arising from changes in production levels.*

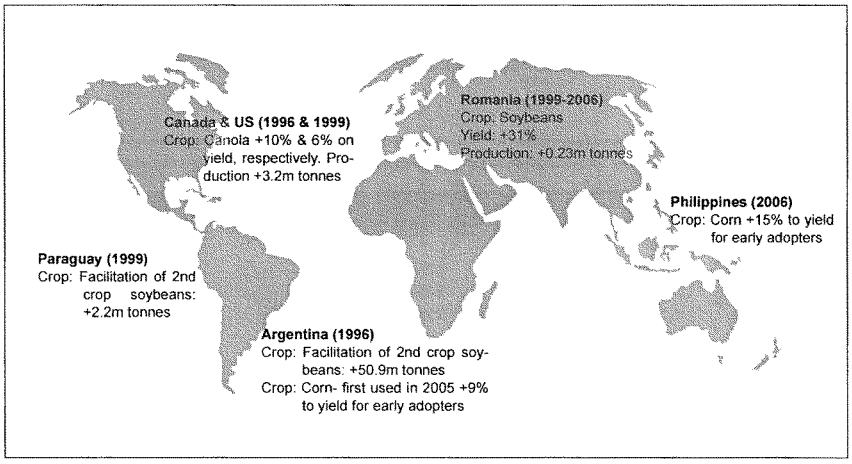


Figure 1. Herbicide-tolerant crops: Yield and production impact of biotechnology 1996-2006 by country.

Production and Yield Impacts of Biotech Traits

IR Corn Impacts. Two biotech IR traits have been commercially used to target the common corn-boring pests—European corn borer or ECB (*Ostrinia nubilalis*) and Mediterranean stem borer or MSB (*Sesamia nonagroides*)—and corn rootworm pests (*Diabrotica*). These are major pests of corn crops in many parts of the world and significantly reduce yield and crop quality, unless crop-protection practices are employed.

The two biotech IR corn traits have delivered positive yield impacts in all user countries when compared to average yields derived from crops using conventional technology (mostly application of insecticides and seed treatments) for control of corn-boring and rootworm pests.

The yield impact varies from an average of about +5% in North America to +24% in the Philippines (Table 1). In terms of additional production, on an area basis, this is in a range of +0.31 tonnes/ha to +0.72 tonnes/ha.

Average yield and production impact across the total area planted to biotech IR corn traits over the 11-year period has been +5.7% (+0.45 tonnes/ha). This has added 47 million tonnes to total corn production in the countries using the technology.

In 2006, the technology delivered an average of 0.47 tonnes/ha in extra production, which was equal to an extra 9.7 million tonnes of corn production (Table 1).

HT Soybeans. Weeds have traditionally been a significant problem for soybean farmers, causing important yield losses (from weed competition for light, nutrients, and water). Most weeds in soybean crops have been reasonably well controlled, based on application of a mix of herbicides.

Although the primary impact of biotech HT technology has been to provide more cost effective (less expensive) and easier weed control versus improving yields from *better weed control* (relative to weed control obtained from conventional technology), improved weed control has, nevertheless occurred, delivering higher yields. Specifically, HT soybeans in Romania improved the average yield by over 30% (Figure 1).

Biotech HT soybeans have also facilitated the adoption of no-tillage production systems, thus shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 53.1 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2006. In 2006, the second-crop soybean production in these countries was 11.6 million tonnes (Table 2).

Table 2. Second crop soybean production facilitated by biotech HT technology in South America 1996-2006 (million tonnes).

Country	Year first commercial use of HT soybean technology	Second-crop soybean production from date of first commercial use to 2006
Argentina	1996	50.9
Paraguay	1999	2.2
Total		53.1

Table 3. Yield impact assumptions: To lower average yields for countries/crops assuming no biotech used from 2008 onwards.

Crop/country	Average yield/production effect on biotech area 2006	% of crop to trait (2006)	Yield impact of technology related to average yield on total crop if no longer used
Corn			
US	+5%	49%	-2.45%
Canada	+5%	50%	-2.45%
Argentina	+7.6%	73%	- 5.55%
Philippines	+24.1%	4%	-0.97%
South Africa	+14.5%	35%	-5.1%
EU-27	+6.1% (Spain)	15% of Spain, 3.3 % of EU-27 area	-0.2% on EU-27 average yield
Soybeans			
EU-27	+31% (Romania)	26% of EU-27 area	-8.1%
Paraguay	+7.5% second crop	7.5%	-7.5%
Argentina	+20% second crop	20%	-20%
Canola			
US	6%	98%	-5.9%
Canada	+3.7%	84%	-3.1%

HT Canola. Weeds represent a significant problem for canola growers because they contribute to reduced yield and impair quality by contamination (e.g., with wild mustard seeds). Conventional canola weed control is based on a mix of herbicides, and it has provided reasonable levels of control, although some resistant weeds have developed (e.g., to the herbicide trifluralin). Canola is also sensitive to herbicide carryover from (herbicide) treatments in preceding crops, which can affect yield.

The main impact of biotech HT canola technology—used widely by canola farmers in Canada and the United States—has been to provide more cost-effective (less expensive) and easier weed control, coupled with higher yields. The higher yields have arisen mainly from more effective levels of weed control than were previously possible using conventional technology. Some farmers have also obtained yield gains from biotech-derived improvements in the yield potential of some HT canola seed.

The average yield impacts have been about +6% (+0.1 tonnes/ha) in the United States and about +10% (+0.15 tonnes/ha) in Canada (Figure 1). Over the 1996-2006 period, the additional North American canola production arising from the use of biotech HT technology was 3.2 million tonnes.

HT Corn. Weeds have also been a significant problem for corn farmers, causing important yield losses. Most weeds in these crops have been reasonably controlled based on application of a mix of herbicides.

The HT technology used in corn has mainly provided more cost-effective (less expensive) and easier weed control rather than improving yields from better weed control (relative to weed control levels obtained from conventional technology).

Improved weed control from use of the HT technology has, nevertheless, delivered higher yields in some regions (Figure 1). For example, in Argentina, where HT corn was first used commercially in 2005, the average yield effect has been +9%, adding +0.36 tonnes/ha to production. Similarly in the Philippines, (first used commercially in 2006), early adopters are finding an average of +15% to yields (+0.72 tonnes/ha).

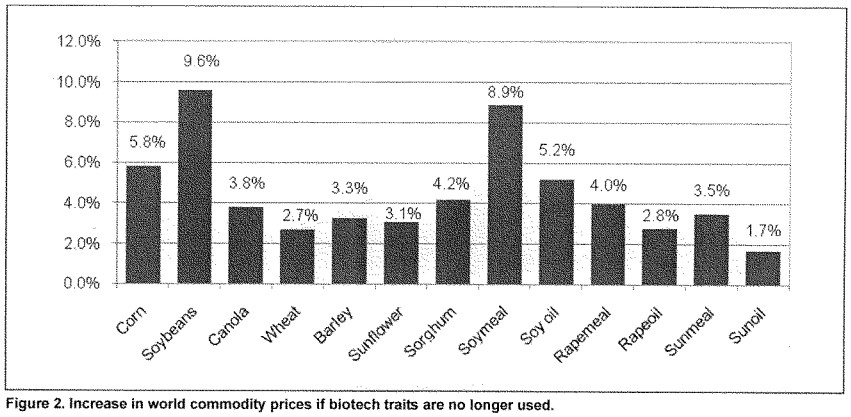


Figure 2. Increase in world commodity prices if biotech traits are no longer used.

Conversion of Production and Yield Impacts into Usable Assumptions

To provide suitable assumptions for input into the agricultural commodity models, the production and yield impacts summarized in the above section (Production and Yield Impacts of Biotech Traits) were converted into national-level yield equivalents. These are presented in Table 3. These yield change assumptions were then introduced into the models to identify impacts of withdrawing the (bio) technology from production systems and hence indirectly identify the impact of the biotech traits to date. The results are presented next.

Impact of Biotech Traits on Prices, Production, Consumption, and Trade in the Cereals and Oilseeds Sectors

World Level

Prices. The running of the agricultural commodity models under the 'no biotech traits' scenario suggests that the impact that these productivity-enhancing biotech traits in corn, soybeans, and canola have had on world prices of both these crops/derivatives and other cereals and oilseeds is significant. We consider the no-biotech scenario as a deviation from the 2007 baseline. In the scenario, the yield shocks are fully implemented from 2008 through 2017. We report the average of these annual changes for the years 2008-2010 as a summary indicator of the short term impacts. The scenario run shows that if these traits were no longer used in global agriculture, the loss of the yield and production-enhancing capabilities of the technology would result in world prices of corn, soybeans, and canola increasing by +5.8%, +9.6%, and +3.8%, respectively (Figure 2). There would also be knock-on effects on the prices of derivatives (e.g., a +9% increase in the world price of soymeal and a +5% increase in the price of soy oil) and other cereals and oilseeds (e.g., increases in prices of +2.7% to +4.2% of wheat, barley, and sorghum). In response to the decline in yields of corn, soybean, and canola, the production of these crops decline and their prices increase. This leads to area reallocation away from wheat, thus increasing its price—though less of an increase relative to corn, soybean, and canola prices. Given the limitations of the analysis (in not including an examination of the impact of the cost-reducing impact of the technology), these estimates of the impact on crop prices are probably understated. Additional information is presented in Appendices B and C to help readers follow how the summary values presented in this section were derived.

In monetary ($ terms), Figure 3 shows the impacts of these price increases relative to the average 2007/08 world price levels.[7]

7. *The impacts presented in Appendix B show the price increases relative to the baseline price levels (average of 2008 through 2010) and are therefore marginally different from the changes presented in Figure 3, which relate to actual 2007/08 average prices. Appendix C summarizes the 2007/08 data used as the base for this figure.*

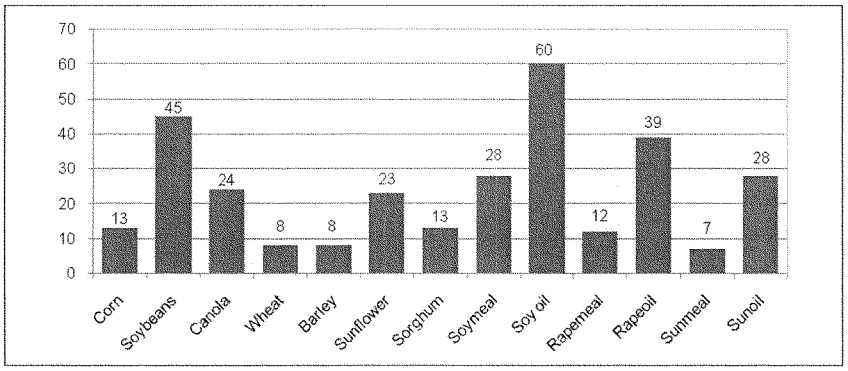


Figure 3. Increase in world commodity prices if biotech traits are no longer used ($/tonne).

Table 4. Global consumption of key commodities/derivatives 2007-08 and impact of price changes.

	Consumption (million tonnes)	Cost of consumption ($ billion)	Additional cost of consumption if biotech traits no longer available ($ billion)
Corn	776.80	169.3	9.82
Wheat	618.10	194.1	5.24
Barley	136.30	33.0	1.09
Sorghum	63.28	18.9	0.79
Soymeal	157.09	49.3	4.39
Soy oil	37.40	43.1	2.24
Canola meal	27.12	8.1	0.32
Canola oil	18.34	25.9	0.72
Sunflower meal	10.43	2.0	0.07
Sunflower oil	9.41	15.4	0.26
Total	**1,854.00**	**559.1**	**24.94**

Sources: Baseline data from USDA Market & Trade reports. Prices based on import/export levels using mainstream ports of trade (USDA). These consumption figures (see Appendix C) differ marginally from the consumption values used in the model baseline presented in Appendix B because they are based on more recent (updated) values to those originally input into the models.

Relating these price changes to global consumption, this is equivalent to adding $25 billion (+4.5%) to the total cost of consumption of these crops/derivatives in 2007/08 (Table 4). The sectors most affected would be the corn- and soybean/derivative-using sectors, although there would also be a significant knock-on effect in the wheat sector.

In terms of income, it is important to recognize that the productivity-enhancing technology has already had an impact on producer (farmer) incomes. The downward world price effects of the technology identified above represent a loss to farmer incomes but a gain to consumers. The negative price effects at the producer level have, though, been more than offset by the direct income gains associated with adoption of the technology for those farmers who have used biotech traits. The direct farm-income gain identified from adoption of biotech traits over the period 1996-2006 was $33.8 billion (Brookes & Barfoot, 2008); this income gain was calculated net (inclusive) of the price effects identified above by using current farm-level prices for each crop, country, and year. In contrast, those farmers who have chosen to not adopt the technology or been denied access to the technology (e.g., on political or regulatory grounds) have experienced the negative price effect but not gained from the yield gains and cost savings associated with using the technology.

Table 5. Potential change to global production base if biotech traits are no longer used.

	Area change (million ha)	Yield (tonnes/ha)	Production (million tonnes)
Corn	+0.48 (+0.3%)	-0.08 (-1.5%)	-9.48 (-1.2%)
Soybeans	+2.27 (+2.5%)	-0.11 (-4.3%)	-4.36 (-2%)
Canola	+0.11 (+0.4%)	-0.01 (-0.65%)	-0.14 (-0.3%)
Soymeal	n/a	n/a	-2.69 (-1.7%)
Soy oil	n/a	n/a	-0.67 (-1.8%)
Canola/ rape meal	n/a	n/a	-0.03 (-0.1%)
Canola/ rape oil	n/a	n/a	-0.04 (-0.2%)

Notes: n/a = not applicable. Baseline for these changes are 2007/08 values. These are marginally different to the model baseline values presented in Appendix B.

Production, Trade and Consumption Impacts. The effect of no longer using the current biotech traits in the corn, soybean, and canola sectors will have an impact on both the supply and utilization of these crops, their derivatives, and related markets for grain and oilseeds.

By taking away the positive yield and production impacts of the technology from the areas planted to these traits, the negative impacts would be felt most in the current-user (technology) countries (see *Production and Yield Assumptions* section). At the global level, the model analysis suggests that the negative impacts on the yields of the three crops are equal to an average reduction of 1.5%, 4.3%, and 0.65%, respectively, for corn, soybeans, and canola (Table 5).

The dynamic effect on subsequent plantings and the production base would result in a projected increase in the total area planted to these three crops of just under 3 million hectares, although this 'compensatory' additional planting would not offset the yield-reduction effects of no longer using biotech traits, resulting in a net fall in global production of the three crops of 14 million tonnes. In respect of the key oilseed derivatives of meal and oil, the reduction in the supply of the base seed (soybeans and rapeseed) would result in knock-on falls in global production of soymeal (1.7%), soy oil (1.8%), rapemeal (0.1%), and rape oil (0.2%). The total reduction in supply of these crops and key derivatives of meal and oil is projected to be 17.4 million tonnes.

The change in the supply availability of these three crops and the resulting upward effect on prices is forecast to lead to falls in global trade of these crops/derivatives. The modelling suggests that world trade in these crops/derivatives would fall by about 6.6 million tonnes, of which the main changes would be decreased trade volumes of 3.2 million tonnes, 1.65 million tonnes, and 1.24 million tonnes for corn, soymeal, and soybeans, respectively.

Table 6. Potential global changes to other grains and oilseeds if biotech traits are no longer used.

	Production (million tonnes)	Consumption (million tonnes)
Wheat	-0.61 (-0.1%)	0.09 (0.01%)
Barley	Nil	+0.10 (+0.07%)
Sorghum	+0.32 (+0.5%)	+0.36 (+0.57%)
Sunflower meal	Nil	+0.02 (+0.2%)
Sunflower oil	Nil	+0.02 (+0.2%)

The model also predicts annual decreases in global consumption of these commodities and derivatives of 14.25 million tonnes. The main decreases in consumption would be for corn (8.07 million tonnes: a 0.98% decrease), soymeal (2.67 million tonnes: 1.7% decrease), and soy oil (0.64 million tonnes: a 1.7% decrease). Change in global consumption of canola/rapeseed derivatives would be marginal.

The analysis also identifies impacts on related grain and oilseed sectors. In addition to the impact on prices (see *IR Corn Impacts* section), the production and consumption of grains such as wheat, barley, sorghum, and oilseeds, notably sunflower, would be affected (Table 6). The global production of wheat is projected to fall by 0.1%, while the production of sorghum would increase by 0.5%. The decline in wheat production is due to area reallocation away from wheat towards crops such as corn, soybean, and canola, which experienced price increases after a yield decline when biotechnology was no longer available. This is in part due to the impact of looking only at the yield impacts of biotech crops, but not at the lower production cost advantages brought about by biotech. In relation to global consumption, this is projected to fall for wheat but increase for barley, sorghum, sunflower meal, and oil.

Taking both the impacts on the three directly affected sectors of corn, soybeans, canola, and related grains and oilseeds, the net impacts of existing biotech traits (if no longer used in global agriculture) are an additional 2.64 million hectares of land being brought into grain and oilseed production. Despite this increase in total planted area, net production of these grains and oilseeds (excluding derivatives) would fall by 14.3 million tonnes. Inclusive of the main oilseed derivatives (including sunflower), net production is forecast to fall by 17.7 million tonnes. World trade in these commodi-

Table 7. Potential change to the US production base if biotech traits are no longer used (% change).

	Area	Average yield	Production	Net trade (net exports)
Corn	-0.8%	-2.5%	-3%	-10%
Soybeans	+3.6%	0%	+3.4%	+14%
Canola	+0.2%	-5.9%	-5.7%	-10%

Table 8. Potential change to the Argentine production base if biotech traits are no longer used (% change).

	Area	Average yield	Production	Net trade (net exports)
Corn	+1.6%	-4.6%	-3.1%	-3.9%
Soybeans	-18.5% (inclusive of loss of second-crop soy)	-0%	-18.8%	-81%
Soymeal	n/a	n/a	-7%	-7%
Soy oil	n/a	n/a	-7%	-8%

Note: n/a = not applicable. The model results presented in Appendix B differ from the changes presented in this table because the model inputs the loss of second-crop soybeans as a yield decrease. The effects presented in this table therefore adjust the negative yield effect used in the modelling to an area change which is projected to be a 1.5% increase in first-crop soybean plantings, relative to a 20% decrease in second-crop soybeans.

ties and derivatives would also fall (by 6.6 million tonnes) and global consumption of these grains and oilseed derivatives is forecast to fall by 15.4 million tonnes. Lastly, the model estimates that the cost of global consumption of these crops and derivatives would increase by $20 billion (3.6%) relative to the total cost of consumption of the (higher) biotech-inclusive level of world consumption. In unit terms, the average cost of consumption would increase by about 4.6% from an average of $301/tonne to $315/tonne.

Country Level

This section discusses the impact at the global level on specific countries and regions of the world of biotech traits no longer being available.

US. If existing biotech traits were no longer available to farmers globally (including US farmers), the impact in the affected US cropping sectors would be significant (Table 7). The model analysis points to production of US corn and canola falling by 3% (10.8 million tonnes) and 5.7% (50,000 tonnes), respectively, mainly due to reduced yields (loss of yield-enhancing nature of the biotech traits). Soybean production, however, would potentially increase by 2.4 million tonnes due to increased plantings of soybeans (the yield losses to corn improving the relative competitive position of soybeans at the farm level).

Trade effects would be similar to the production impacts, with decreases in the volumes of exported corn and canola of about 10%. Soybean exports, however, would potentially increase significantly due to the additional production. The model also forecasts knock-on effects in other sectors; plantings of wheat and sorghum would be expected to fall, resulting in decreased production of these crops (0.6% for wheat and 0.5% for sorghum). In contrast, plantings and production of barley are expected to increase by 1.1%. Lastly, domestic US consumption of corn, soybeans, and canola is expected to fall by 2%, 0.5%, and 2%, respectively (caused by the higher price; see *Prices* section).

Argentina. The effect of no longer using biotech traits globally in the Argentine corn and soybean sectors is summarized in Table 8. Production of corn is forecast to fall by 3.1% (about 0.7 million tonnes) due to reduced yields (loss of yield-enhancing nature of the biotech traits). Output of soybeans is predicted to fall more significantly because of the negative effect on second-crop soybeans, which accounted for 20%-plus of the total Argentine soybean crop in 2006 (GM HT technology having contributed to shortening the production cycle for soybeans allowing many farmers to plant a crop of soybeans after wheat in the same season). As such, no longer having access to this technology would potentially threaten plantings of second-crop soy, resulting in a significant fall in total soybean production (equal to almost 9 million tonnes).

The declines in production of soybeans and corn would have an important negative impact on the wider Argentine economy. Domestic consumption of both corn and soybeans is forecast to fall by about 1% and 7%, respectively (due to reduced availability and higher prices). More importantly, the reduced levels of production would result in decreased volumes available for export, especially in the soybean and derivative sectors. Given that soybean exports have contributed and will continue to contribute tax revenues to the Argentine

Table 9. Potential change to the Canadian production base if biotech traits are no longer used (% change).

	Area	Average yield	Production	Net trade (net exports)
Corn	+0.4%	-2.5%	-2.1%	+5.6%
Soybeans	+2.2%	0%	+2.2%	+8.8%
Canola	+0.2%	-3.1%	-2.9%	-1.5%
Soymeal	n/a	n/a	-1.8%	-3.3%
Soy oil	n/a	n/a	-1.8%	-3.3%
Canola/ rape meal	n/a	n/a	-5.3%	-6.8%
Canola/ rape oil	n/a	n/a	-5.3%	-6.8%
Wheat	-0.14%	0%	-0.14%	0.13%

Note: n/a = not applicable

Exchequer, this would result in important cuts in government tax revenues. Lastly, the modelling results suggest that production of other cereals, notably wheat and barley, would potentially increase by over 1% due to increased plantings of these crops.

Canada. The estimated impact of no longer making available the existing biotech traits in the global corn, soybean, and canola markets on the relevant Canadian cropping sectors is summarized in Table 9. Production of corn and canola is forecast to fall by more than 2% (0.3 million tonnes for corn and 0.3 million tonnes of canola) due to reduced yields (loss of yield-enhancing nature of the biotech traits). Soybean production, however, would likely increase (by more than 2%) because of increased plantings (as in the United States, the yield losses to corn improving the relative competitive position of soybeans at the farm level). The model predicts that domestic consumption and use of all three commodities and derivatives would fall (by more than 4% for both soybeans and canola and by about 1% for corn) due to higher prices (see *World Level* section). Canada, a net importer of corn, increases its net imports because of the decline in production. Exports of soybeans, however, would potentially increase as decreased domestic consumption results in additional volumes becoming available for export. In contrast, exports of canola and derivatives would be expected to fall—exports being a major outlet for Canadian canola relative to domestic consumption; hence, any additional supplies available for export from reduced domestic consumption would be more than offset by the fall in production associated with the withdrawal of biotech traits. The changes in biotech crops also impact the other crop markets. With the increase in corn prices, wheat area in Canada declines as area shifts away from wheat to corn. This increases wheat prices and thus domestic use of wheat declines. Net exports of wheat in Canada increase since domestic use declines more than domestic supply because of the relatively larger decline in stocks of wheat.

South Africa and the Philippines—Corn Sector. Both these countries currently use biotech IR technology in their corn sectors. Consequently, if this technology was no longer available to these and all farmers globally, there would be important negative impacts for those farmers who currently use the technology. At the national level in South Africa, average corn yields would be expected to fall by more than 5%, resulting in a net 5.5% reduction in total corn production.[8] In the Philippines, where adoption of biotech IR corn traits is more recent—and hence less widespread than in South Africa (5% of total crop compared to 63% of the total corn crop in South Africa)—the national-level impacts are an average decrease in corn yield of 1% and production falling by about 0.5%.[9]

The modelling results suggest that domestic consumption of corn is also expected to fall by more than 1.5% in both countries (due to higher prices of corn). In terms of net trade, imports in the Philippines would increase by about 0.1 million tonnes (50%), while in South Africa, exports (of corn) would fall by nearly 30% (about 0.45 million tonnes).

The European Union. There were two biotech traits in use commercially in EU-27 countries of relevance during the 1998-2006 period: IR corn in several member states and HT soybeans in Romania. The modelling analysis identifies negative impacts of no longer using these technologies (both in the EU and globally).[10] Average EU-27 corn yields and production would be expected to fall marginally (by 0.2%),[11] while both con-

8. *Area planted is projected to fall by 0.5%.*
9. *Area planted is projected to increase by 0.7%.*
10. *The removal of access to this technology has, in fact, occurred in relation to herbicide tolerant soybeans in Romania, which joined the EU in 2007, and hence, had to adopt EU regulations relating to biotechnology—the planting of biotech herbicide tolerant soybeans is currently not permitted in the EU-27.*
11. *Readers should note that biotech IR corn was planted on about 0.1 million hectares in the EU-27 in 2007, equal to 1.3% of total EU-27 corn planting.*

sumption and net trade (imports) of corn would fall by 0.3% and 1.2%, respectively (negative effect of higher world prices for corn). Average soybean yields across the EU would also be expected to fall by -3.2%, and production would be lower by -1.3% due to the negative effect on yields and production of soybeans in the important EU soybean-producing country of Romania. This reduced supply of domestic soybeans is forecast to result in reductions in the EU production of soymeal and soy oil (by 1.1%). Usage of soymeal and soy oil is also forecast to fall by 2.6% and 1.4%, respectively (due to higher world prices).

Conclusions

This study quantified, through the use of agricultural commodity models, the impact of biotech traits on production, usage, trade, and prices in the corn, soybean, and canola sectors. The previous analysis (Brookes & Barfoot, 2008) estimated that biotech crops, through the two main traits of insect resistance and herbicide tolerance have, during the 1996-2006 period, added 53.3 million tonnes and 47.1 million tonnes, respectively, to global production of soybeans and corn. The technology has also contributed an extra 3.2 million tonnes of canola.

The estimated impact of these additional volumes of production on markets and prices in the cereals and oilseeds sectors has been significant. Our modelling analysis of the potential impact of no longer using these traits in world agriculture shows that the world prices of these commodities, their key derivatives, and related cereal and oilseed crops would be significantly affected. World prices of corn, soybeans, and canola would probably be respectively 5.8%, 9.6%, and 3.8% higher than the baseline 2007 levels (when the technology was available for the analysis purposes). Prices of key derivatives of soybeans (meal and oil) would also be between 5% (oil) and 9% (meal) higher than the baseline levels, with rapeseed meal and oil prices being about 4% higher than baseline levels. World prices of related cereals and oilseeds would also be expected to rise by 3-4%.

The effect of no longer using the current biotech traits in the corn, soybean, and canola sectors would also impact both the supply and utilization of these crops, their derivatives, and related markets for grain and oilseeds. Average global yields are estimated to fall by 1.5%, 4.3%, and 0.65% for corn, soybeans, and canola, respectively. While there is likely to be some 'compensatory' additional plantings (of just under 3 million hectares) of these three crops, this would not offset the yield-reduction effects of no longer using biotech traits, thus resulting in a net fall in global production of the three crops of 14 million tonnes. The modelling also suggests that a fall in the supply availability of these three crops and the resulting upward effect on prices would lead to a projected decrease in global trade of these crops/derivatives of 6.6 million tonnes, a 1.4% decrease in corn usage and a 1.7% decrease in usage of soymeal and soy oil (changes in global consumption of canola/rapeseed derivatives would be marginal).

The production and consumption of grains such as wheat, barley, and sorghum and oilseeds, notably sunflower, would also be affected (e.g., the global production and consumption of wheat would fall by 0.1% and 0.01%, respectively).

Overall, the net impacts of existing biotech traits (if no longer used) in global agriculture are that an additional 2.64 million hectares of land would probably be brought into grain and oilseed production. Despite this, net production of grains and oilseeds (including derivatives) would potentially fall by 17.7 million tonnes[12] and global consumption would potentially fall by 15.4 million tonnes. The cost of consumption would also increase by $20 billion (3.6%) relative to the total cost of consumption of the (higher) biotech-inclusive level of world consumption. In unit terms, the net cost of consumption would increase by about 4.6%.

The impacts identified in this analysis are probably conservative, reflecting the limitations of the methodology used to estimate the productivity-enhancing effects of biotech traits so far used in global agriculture. In particular, the limited research conducted to date into the impact of the cost-reducing effect of biotechnology (notably in HT soybeans) on prices and the assumption of using 2007 levels of biotech adoption as the 'counterfactual' position suggests that the price effects identified in this article represent only part of the total price impact of the technology. Subsequent research might usefully extend this analysis to incorporate consideration of the cost-reducing effect of the technology (especially HT technology), a more dynamic counterfactual position, and to examination of the cotton sector.

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Appendix A: Agricultural Modelling System—Methodological Details

General Description of the Modelling System

This study uses part of a broad modelling system of world agricultural economy comprised of US and international multi-market, partial-equilibrium models. The models are econometric and simulation models covering all major temperate crops, sugar, ethanol and bio-diesel, dairy, and livestock and meat products for all major producing and consuming countries and calibrated on most recently available data. A Rest-of-the-World aggregate is included to close the models. Table A1 presents a detailed list of commodity and country coverage. Extensive market linkages exist in these models, reflecting derived demand for feed in livestock and dairy sectors, competition for land in production, and consumer substitution possibilities for close substitutes such as vegetable oils and meat types.

The models capture the biological, technical, and economic relationships among key variables within a particular commodity and across commodities. They are based on historical data analysis, current academic research, and a reliance on accepted economic, agronomic, and biological relationships in agricultural production and markets. A link is made through prices and net trade equations between the US and international models. The models are used to establish commodity projections for a baseline and for policy analysis, and are used extensively for the market outlook and policy analysis. This set of agricultural models have been used in a number of studies including Elobeid et al. (2007), Fabiosa et al. (2005, 2007), and Tokgoz et al. (2008).

In general, for each commodity sector, the economic relationship that supply equals demand is maintained by determining a market-clearing price for the commodity. In countries where domestic prices are not solved endogenously, these prices are modelled as a function of the world price using a price transmission equation. Since econometric models for each sector can be linked, changes in one commodity sector will impact other sectors. A detailed description of the models is available on Iowa State University's FAPRI website.[13] Figure A1 provides a diagram of the overall modelling system. For this particular study, the US Crops, International Grains, International Oilseed, International Sugar, and International Bio-fuels models were used.

More specifically in terms of the structure of the models, the following identity is satisfied for each country/region and the world:

Beginning Stock + Production + Imports = Ending Stock + Consumption + Exports

13. *http://www.fapri.iastate.edu/models/*

Table A1. Model inputs and output.

Commodities	Major countries/regions	Exogenous inputs	Historical data (inputs)	Output by commodity and country
Grains	**North America**	Population	Production	World prices
Corn	United States,	GDP	Consumption	Domestic prices
Wheat	Canada, Mexico	GDP deflator	Exports	Production
Sorghum		Exchange rate	Imports	Consumption
Barley	**South America**	Population	Ending stocks	Net trade
	Brazil, Argentina,Colombia,	Policy variables	Domestic prices	Stocks
Oilseeds	etc.		World prices	Area harvested
Soybeans				Yield
Rapeseed	**Asia**			
Sunflower	China, Japan, India,			
	Indonesia, Malaysia, etc.			
Sugar				
	Africa			
Biofuels	South Africa, Egypt, etc.			
Ethanol				
Biodiesel	**European Union**			
	Oceania			
	Australia			
	Middle East			
	Iran, Saudi Arabia, etc.			
	Rest of the World			

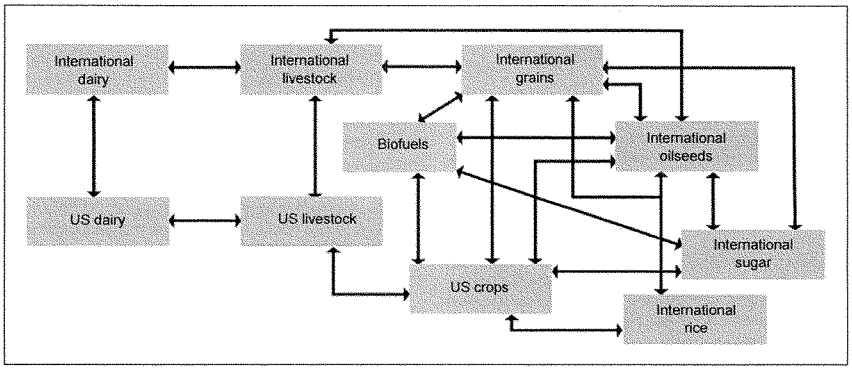


Figure A1. Model interactions: Trade, prices and physical flows.

Production is divided into yield and area equations, while consumption is divided into feed and non-feed demand. The models include behavioral equations for area harvested, yield, crop production on the supply side, and per-capita consumption and ending stocks on the demand side. Equilibrium prices, quantities, and net trade are determined by equating excess supply and excess demand across countries and regions. To satisfy the identity in Equation 1, two different methods are used. In most of the countries, domestic price is modelled as a function of the world price with a price transmission equation, and the identity is satisfied with one of the variables set as the residual. In other cases, prices are solved to satisfy the identity.

Agricultural and trade policies in each country are included in the models to the extent that they affect the

supply and demand decisions of the economic agents. Examples of these include taxes on exports and imports, tariffs, tariff rate quotas, export subsidies, intervention prices, and set-aside rates. The models assume that the existing agricultural and trade policy variables will remain unchanged in the outlook period. Macroeconomic variables, such as GDP, population, and exchange rates, are exogenous variables that drive the projections of the model. The models also include an adjustment for marketing-year differences by including a residual that is equal to world exports minus world imports, which ensures that world demand equals world supply.

All models are calibrated on 2007/08 marketing year data for crops and 2007 calendar year data for livestock and biofuels, and 10-year projections for supply and utilization of commodities and prices are generated for the period between 2008 and 2017. The models also adjust for marketing-year differences by including a residual that is equal to world exports minus world imports, which ensures that world demand equals world supply. Elasticity values for supply and demand responses are based on econometric analysis and on consensus estimates. Elasticity parameters estimates and policy variables are available in Iowa State University's FAPRI's Elasticity Database.[14]

Data for commodity supply and utilization are obtained from the F.O. Lichts online database, the Food and Agriculture Organization (FAO) of the United Nations (FAOSTAT Online, 2006), the Production, Supply and Distribution View (PS&D) of the US Department of Agriculture (USDA), the European Commission Directorate General for Energy and Transport, the ANFAVEA (2005), and UNICA (2006). Supply and utilization data include production, consumption, net trade, and stocks. The macroeconomic data are gathered from the International Monetary Fund and Global Insight.

14. *http://www.fapri.iastate.edu/tools/*

Appendix B. Scenario Results

Table B1. Wheat prices.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
US FOB Gulf				(US dollars per metric ton)						
Baseline	251.95	252.04	258.65	257.80	261.80	264.06	266.98	270.41	272.93	273.75
Scenario 1	255.89	260.37	267.10	264.47	268.57	271.17	273.74	276.99	279.76	280.78
% change	1.56%	3.31%	3.27%	2.58%	2.59%	2.69%	2.53%	2.43%	2.50%	2.57%
Canadian Wheat Board										
Baseline	262.60	262.06	267.48	266.15	269.33	270.37	271.87	274.00	275.66	276.48
Scenario 1	265.99	269.20	274.65	271.77	275.07	276.40	277.61	279.59	281.47	282.47
% change	1.29%	2.73%	2.68%	2.11%	2.13%	2.23%	2.11%	2.04%	2.11%	2.16%
AWB limited export quote										
Baseline	252.70	251.43	257.05	256.47	259.85	261.86	264.39	267.37	269.58	270.34
Scenario 1	256.04	258.60	264.41	262.32	265.75	268.04	270.28	273.11	275.53	276.45
% change	1.32%	2.85%	2.86%	2.28%	2.27%	2.36%	2.23%	2.15%	2.21%	2.26%
European Union market										
Baseline	270.66	252.49	241.79	237.26	231.78	230.18	231.70	233.38	235.10	236.16
Scenario 1	274.11	255.21	244.21	239.81	234.39	232.74	234.34	236.12	237.94	239.14
% change	1.27%	1.08%	1.00%	1.08%	1.13%	1.11%	1.14%	1.17%	1.21%	1.26%

Table B2. Wheat prices.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
US FOB Gulf				(US dollars per metric ton)						
Baseline	251.95	252.04	258.65	257.80	261.80	264.06	266.98	270.41	272.93	273.75
Scenario 1	255.89	260.37	267.10	264.47	268.57	271.17	273.74	276.99	279.76	280.78
% change	1.56%	3.31%	3.27%	2.58%	2.59%	2.69%	2.53%	2.43%	2.50%	2.57%
Canadian Wheat Board										
Baseline	262.60	262.06	267.48	266.15	269.33	270.37	271.87	274.00	275.66	276.48
Scenario 1	265.99	269.20	274.65	271.77	275.07	276.40	277.61	279.59	281.47	282.47
% change	1.29%	2.73%	2.68%	2.11%	2.13%	2.23%	2.11%	2.04%	2.11%	2.16%
AWB limited export quote										
Baseline	252.70	251.43	257.05	256.47	259.85	261.86	264.39	267.37	269.58	270.34
Scenario 1	256.04	258.60	264.41	262.32	265.75	268.04	270.28	273.11	275.53	276.45
% change	1.32%	2.85%	2.86%	2.28%	2.27%	2.36%	2.23%	2.15%	2.21%	2.26%
European Union market										
Baseline	270.66	252.49	241.79	237.26	231.78	230.18	231.70	233.38	235.10	236.16
Scenario 1	274.11	255.21	244.21	239.81	234.39	232.74	234.34	236.12	237.94	239.14
% change	1.27%	1.08%	1.00%	1.08%	1.13%	1.11%	1.14%	1.17%	1.21%	1.26%

Table B3. World wheat supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
Area harvested				(Thousand hectares)						
Baseline	222,149	221,970	219,530	220,580	220,862	220,987	221,245	221,363	221,426	221,668
Scenario 1	222,096	221,555	219,352	220,685	220,838	220,943	221,229	221,338	221,386	221,626
% change	-0.02%	-0.19%	-0.08%	0.05%	-0.01%	-0.02%	-0.01%	-0.01%	-0.02%	-0.02%
Yield				(Metric tons per hectare)						
Baseline	2.92	2.93	2.96	2.98	3.00	3.03	3.05	3.07	3.10	3.12
Scenario 1	2.92	2.93	2.96	2.98	3.00	3.03	3.05	3.07	3.10	3.12
% change	-0.02%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Production				(Thousand metric tons)						
Baseline	648,567	650,692	649,049	657,034	662,973	668,541	674,503	680,056	685,459	691,360
Scenario 1	648,294	649,468	648,582	657,345	662,873	668,398	674,438	679,951	685,304	691,199
% change	-0.04%	-0.19%	-0.07%	0.05%	-0.02%	-0.02%	-0.01%	-0.02%	-0.02%	-0.02%
Beginning stocks										
Baseline	111,043	128,080	133,956	134,678	136,261	137,314	138,218	138,988	139,655	140,416
Scenario 1	111,043	127,138	131,963	132,452	134,419	135,564	136,444	137,304	138,047	138,804
% change	0.00%	-0.74%	-1.49%	-1.65%	-1.35%	-1.27%	-1.28%	-1.21%	-1.15%	-1.15%
Domestic supply										
Baseline	759,610	778,772	783,005	791,712	799,235	805,854	812,720	819,044	825,114	831,777
Scenario 1	759,337	776,605	780,545	789,797	797,292	803,962	810,882	817,254	823,350	830,003
% change	-0.04%	-0.28%	-0.31%	-0.24%	-0.24%	-0.23%	-0.23%	-0.22%	-0.21%	-0.21%
Feed use										
Baseline	106,204	110,104	110,389	111,272	112,283	112,932	113,533	114,211	114,658	115,137
Scenario 1	106,652	110,543	110,836	111,712	112,657	113,336	113,921	114,568	115,024	115,514
% change	0.42%	0.40%	0.41%	0.40%	0.33%	0.36%	0.34%	0.31%	0.32%	0.33%
Food and other										
Baseline	525,325	534,712	537,938	544,178	549,639	554,705	560,199	565,178	570,040	575,047

Table B3. World wheat supply and utilization.

Scenario 1	525,547	534,099	537,258	543,666	549,071	554,181	559,657	564,640	569,522	574,524
% change	0.04%	-0.11%	-0.13%	-0.09%	-0.10%	-0.09%	-0.10%	-0.10%	-0.09%	-0.09%
Ending stocks										
Baseline	128,080	133,956	134,678	136,261	137,314	138,218	138,988	139,655	140,416	141,593
Scenario 1	127,138	131,963	132,452	134,419	135,564	136,444	137,304	138,047	138,804	139,965
% change	-0.74%	-1.49%	-1.65%	-1.35%	-1.27%	-1.28%	-1.21%	-1.15%	-1.15%	-1.15%
Domestic use										
Baseline	759,610	778,772	783,005	791,712	799,235	805,854	812,720	819,044	825,114	831,777
Scenario 1	759,337	776,605	780,545	789,797	797,292	803,962	810,882	817,254	823,350	830,003
% change	-0.04%	-0.28%	-0.31%	-0.24%	-0.24%	-0.23%	-0.23%	-0.22%	-0.21%	-0.21%
Trade *										
Baseline	89,343	94,120	94,202	95,988	98,715	100,937	103,167	105,148	106,888	108,747
Scenario 1	89,429	94,198	94,095	95,910	98,588	100,845	103,045	105,056	106,839	108,694
% change	0.10%	0.08%	-0.11%	-0.08%	-0.13%	-0.09%	-0.12%	-0.09%	-0.05%	-0.05%
Stocks-to-use ratio					**(Percent)**					
Baseline	20.28	20.77	20.77	20.79	20.74	20.70	20.63	20.56	20.51	20.52
Scenario 1	20.11	20.47	20.44	20.51	20.49	20.44	20.38	20.32	20.28	20.28
% change	-0.84%	-1.46%	-1.62%	-1.34%	-1.25%	-1.27%	-1.19%	-1.13%	-1.13%	-1.13%

** Excludes international trade*

Table B4. Coarse grain prices.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
Corn (FOB Gulf)				**(US dollars per metric ton)**						
Baseline	196	216	209	209	215	215	217	221	221	220
Scenario 1	206	229	222	219	226	226	227	231	231	231
% change	4.97%	6.32%	6.08%	4.89%	4.80%	5.17%	4.73%	4.51%	4.78%	4.94%
Sorghum (FOB Gulf)										
Baseline	175	191	183	184	189	188	191	194	195	195
Scenario 1	181	199	192	191	196	195	197	201	202	202
% change	3.64%	4.60%	4.49%	3.50%	3.56%	3.87%	3.47%	3.36%	3.61%	3.71%
Barley (Canada feed)										
Baseline	146	153	153	154	158	161	164	169	172	175
Scenario 1	149	159	159	159	162	166	169	173	177	180
% change	2.15%	3.87%	3.89%	3.21%	2.96%	3.14%	2.95%	2.71%	2.78%	2.85%
Corn (EU)										
Baseline	259.24	234.42	224.72	221.50	217.38	215.39	216.36	217.33	217.60	217.06
Scenario 1	264.28	238.93	228.88	225.46	221.36	219.47	220.41	221.42	221.88	221.53
% change	1.94%	1.93%	1.85%	1.79%	1.83%	1.89%	1.87%	1.88%	1.97%	2.06%
Barley (EU)										
Baseline	244.80	225.86	217.26	213.89	209.27	207.91	209.25	210.64	211.87	212.54
Scenario 1	247.67	228.19	219.26	216.01	211.43	210.04	211.45	212.90	214.21	215.00
% change	1.17%	1.03%	0.92%	0.99%	1.03%	1.03%	1.05%	1.07%	1.11%	1.16%

Table B4. World corn supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
Area harvested					(Thousand hectares)					
Baseline	160,424	161,061	166,781	168,047	167,954	170,035	170,820	171,280	172,286	172,931
Scenario 1	160,599	161,436	167,628	169,176	168,638	170,345	171,256	171,616	172,407	173,089
% change	0.11%	0.23%	0.51%	0.67%	0.41%	0.18%	0.26%	0.20%	0.07%	0.09%
Yield					(Metric tons per hectare)					
Baseline	4.96	5.03	5.14	5.25	5.31	5.39	5.47	5.53	5.60	5.67
Scenario 1	4.90	4.95	5.05	5.17	5.22	5.29	5.37	5.43	5.50	5.56
% change	-1.18%	-1.60%	-1.72%	-1.61%	-1.60%	-1.76%	-1.78%	-1.75%	-1.82%	-1.84%
Production					(Thousand metric tons)					
Baseline	795,217	810,266	856,591	882,789	891,255	915,958	934,479	947,376	964,302	980,380
Scenario 1	786,714	799,131	846,138	874,440	880,580	901,471	920,223	932,587	947,439	963,237
% change	-1.07%	-1.37%	-1.22%	-0.95%	-1.20%	-1.58%	-1.53%	-1.56%	-1.75%	-1.75%
Beginning stocks										
Baseline	102,533	103,581	97,074	101,584	106,107	103,897	105,121	106,391	105,725	106,354
Scenario 1	102,533	100,234	91,708	95,717	101,391	99,763	100,321	101,790	101,531	101,839
% change	0.00%	-3.23%	-5.53%	-5.78%	-4.44%	-3.98%	-4.57%	-4.33%	-3.97%	-4.24%
Domestic supply										
Baseline	897,750	913,848	953,665	984,374	997,362	1,019,854	1,039,600	1,053,768	1,070,027	1,086,734
Scenario 1	889,248	899,365	937,846	970,158	981,971	1,001,234	1,020,544	1,034,377	1,048,969	1,065,076
% change	-0.95%	-1.58%	-1.66%	-1.44%	-1.54%	-1.83%	-1.83%	-1.84%	-1.97%	-1.99%
Feed use										
Baseline	490,514	486,098	497,113	506,626	509,382	517,178	523,330	527,204	532,514	538,892
Scenario 1	487,048	480,003	490,879	501,903	504,689	511,585	518,109	522,215	527,057	533,278
% change	-0.71%	-1.25%	-1.25%	-0.93%	-0.92%	-1.08%	-1.00%	-0.95%	-1.02%	-1.04%
Food and other										
Baseline	303,655	330,676	354,968	371,640	384,084	397,555	409,878	420,839	431,159	439,609
Scenario 1	301,966	327,653	351,250	366,864	377,519	389,329	400,645	410,631	420,073	428,408
% change	-0.56%	-0.91%	-1.05%	-1.29%	-1.71%	-2.07%	-2.25%	-2.43%	-2.57%	-2.55%
Ending stocks										
Baseline	103,581	97,074	101,584	106,107	103,897	105,121	106,391	105,725	106,354	108,233
Scenario 1	100,234	91,708	95,717	101,391	99,763	100,321	101,790	101,531	101,839	103,390
% change	-3.23%	-5.53%	-5.78%	-4.44%	-3.98%	-4.57%	-4.33%	-3.97%	-4.24%	-4.47%
Domestic use										
Baseline	897,750	913,848	953,665	984,374	997,362	1,019,854	1,039,600	1,053,768	1,070,027	1,086,734
Scenario 1	889,248	899,365	937,846	970,158	981,971	1,001,234	1,020,544	1,034,377	1,048,969	1,065,076
% change	-0.95%	-1.58%	-1.66%	-1.44%	-1.54%	-1.83%	-1.83%	-1.84%	-1.97%	-1.99%
Trade *										
Baseline	85,330	82,314	83,886	86,491	87,216	89,114	91,056	92,342	94,072	96,335
Scenario 1	83,408	79,105	80,681	83,874	84,859	86,613	88,685	90,151	91,852	94,045
% change	-2.25%	-3.90%	-3.82%	-3.03%	-2.70%	-2.81%	-2.60%	-2.37%	-2.36%	-2.38%
Stocks-to-use ratio					(Percent)					
Baseline	13.04	11.89	11.92	12.08	11.63	11.49	11.40	11.15	11.04	11.06
Scenario 1	12.70	11.35	11.37	11.67	11.31	11.14	11.08	10.88	10.75	10.75
% change	-2.60%	-4.46%	-4.66%	-3.40%	-2.75%	-3.10%	-2.82%	-2.40%	-2.57%	-2.80%

** Excludes intraregional trade*

Table B5. World barley supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
Area harvested					(Thousand hectares)					
Baseline	56,910	56,795	57,012	57,019	57,048	57,086	57,213	57,237	57,304	57,387
Scenario 1	56,895	56,761	57,024	57,044	57,071	57,093	57,225	57,255	57,316	57,397
% change	-0.03%	-0.06%	0.02%	0.04%	0.04%	0.01%	0.02%	0.03%	0.02%	0.02%
Yield					(Metric tons per hectare)					
Baseline	2.53	2.55	2.56	2.57	2.59	2.60	2.62	2.63	2.64	2.65
Scenario 1	2.53	2.55	2.56	2.57	2.59	2.60	2.62	2.63	2.64	2.65
% change	-0.03%	0.05%	0.05%	0.04%	0.02%	0.03%	0.03%	0.02%	0.02%	0.02%
Production					(Thousand metric tons)					
Baseline	144,105	144,573	145,914	146,705	147,629	148,556	149,633	150,443	151,326	152,241
Scenario 1	144,027	144,556	146,021	146,822	147,725	148,619	149,706	150,527	151,393	152,306
% change	-0.05%	-0.01%	0.07%	0.08%	0.07%	0.04%	0.05%	0.06%	0.04%	0.04%
Beginning stocks										
Baseline	15,413	18,066	18,557	19,015	19,259	19,355	19,455	19,562	19,605	19,710
Scenario 1	15,413	17,876	18,260	18,718	19,005	19,115	19,201	19,319	19,377	19,475
% change	0.00%	-1.05%	-1.60%	-1.56%	-1.32%	-1.24%	-1.30%	-1.24%	-1.17%	-1.19%
Domestic supply										
Baseline	159,518	162,639	164,471	165,720	166,888	167,912	169,088	170,005	170,931	171,951
Scenario 1	159,440	162,432	164,281	165,540	166,730	167,733	168,907	169,847	170,769	171,781
% change	-0.05%	-0.13%	-0.12%	-0.11%	-0.09%	-0.11%	-0.11%	-0.09%	-0.09%	-0.10%
Feed use										
Baseline	97,028	98,901	99,685	100,262	100,904	101,440	102,101	102,621	103,072	103,537
Scenario 1	97,166	99,042	99,843	100,390	101,033	101,564	102,213	102,738	103,191	103,655
% change	0.14%	0.14%	0.16%	0.13%	0.13%	0.12%	0.11%	0.11%	0.12%	0.11%
Food and other										
Baseline	44,424	45,181	45,772	46,198	46,629	47,017	47,425	47,778	48,149	48,524
Scenario 1	44,397	45,130	45,720	46,145	46,583	46,968	47,375	47,732	48,103	48,477
% change	-0.06%	-0.11%	-0.11%	-0.11%	-0.10%	-0.10%	-0.11%	-0.10%	-0.10%	-0.10%
Ending stocks										
Baseline	18,066	18,557	19,015	19,259	19,355	19,455	19,562	19,605	19,710	19,890
Scenario 1	17,876	18,260	18,718	19,005	19,115	19,201	19,319	19,377	19,475	19,650
% change	-1.05%	-1.60%	-1.56%	-1.32%	-1.24%	-1.30%	-1.24%	-1.17%	-1.19%	-1.21%
Domestic use										
Baseline	159,518	162,639	164,471	165,720	166,888	167,912	169,088	170,005	170,931	171,951
Scenario 1	159,440	162,432	164,281	165,540	166,730	167,733	168,907	169,847	170,769	171,781
% change	-0.05%	-0.13%	-0.12%	-0.11%	-0.09%	-0.11%	-0.11%	-0.09%	-0.09%	-0.10%
Trade *										
Baseline	15,871	16,721	17,067	17,246	17,430	17,539	17,648	17,729	17,783	17,829
Scenario 1	15,918	16,786	17,110	17,270	17,454	17,565	17,669	17,749	17,804	17,850
% change	0.30%	0.39%	0.25%	0.14%	0.14%	0.15%	0.12%	0.11%	0.12%	0.11%
Stocks-to-use ratio					(Percent)					
Baseline	12.77	12.88	13.07	13.15	13.12	13.10	13.08	13.04	13.03	13.08
Scenario 1	12.63	12.67	12.86	12.97	12.95	12.93	12.92	12.88	12.87	12.92
% change	-1.13%	-1.66%	-1.63%	-1.37%	-1.30%	-1.35%	-1.28%	-1.21%	-1.24%	-1.25%

* *Excludes intraregional trade*

Table B6. World sorghum supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
Area harvested					(Thousand hectares)					
Baseline	41,252	40,889	41,670	41,378	41,134	41,487	41,507	41,724	41,976	42,008
Scenario 1	41,265	41,116	41,983	41,694	41,366	41,732	41,796	41,984	42,233	42,296
% change	0.03%	0.56%	0.75%	0.76%	0.56%	0.59%	0.70%	0.62%	0.61%	0.69%
Yield					(Metric tons per hectare)					
Baseline	1.54	1.53	1.54	1.56	1.57	1.59	1.60	1.61	1.62	1.64
Scenario 1	1.54	1.53	1.54	1.56	1.57	1.59	1.60	1.61	1.63	1.64
% change	0.05%	0.03%	0.01%	0.04%	0.06%	0.04%	0.05%	0.05%	0.04%	0.05%
Production					(Thousand metric tons)					
Baseline	63,439	62,547	64,362	64,602	64,739	65,874	66,423	67,263	68,200	68,820
Scenario 1	63,494	62,915	64,850	65,122	65,143	66,286	66,917	67,718	68,648	69,325
% change	0.09%	0.59%	0.76%	0.81%	0.62%	0.63%	0.74%	0.68%	0.66%	0.73%
Beginning stocks										
Baseline	3,972	4,372	4,013	4,174	4,257	4,229	4,308	4,320	4,304	4,334
Scenario 1	3,972	4,273	3,853	3,998	4,110	4,085	4,151	4,176	4,166	4,187
% change	0.00%	-2.26%	-3.99%	-4.22%	-3.46%	-3.41%	-3.64%	-3.34%	-3.21%	-3.38%
Domestic supply										
Baseline	67,411	66,919	68,376	68,776	68,997	70,103	70,731	71,583	72,505	73,154
Scenario 1	67,466	67,189	68,703	69,120	69,253	70,371	71,068	71,894	72,814	73,513
% change	0.08%	0.40%	0.48%	0.50%	0.37%	0.38%	0.48%	0.43%	0.43%	0.49%
Feed use										
Baseline	26,931	26,123	26,534	26,529	26,630	26,808	26,791	26,846	26,937	26,999
Scenario 1	27,069	26,288	26,686	26,691	26,759	26,933	26,929	26,966	27,049	27,117
% change	0.51%	0.63%	0.57%	0.61%	0.48%	0.47%	0.51%	0.45%	0.42%	0.44%
Food and other										
Baseline	36,108	36,783	37,668	37,989	38,138	38,987	39,620	40,432	41,234	41,774
Scenario 1	36,123	37,048	38,020	38,319	38,409	39,287	39,963	40,761	41,578	42,165
% change	0.04%	0.72%	0.94%	0.87%	0.71%	0.77%	0.87%	0.81%	0.83%	0.94%
Ending stocks										
Baseline	4,372	4,013	4,174	4,257	4,229	4,308	4,320	4,304	4,334	4,381
Scenario 1	4,273	3,853	3,998	4,110	4,085	4,151	4,176	4,166	4,187	4,231
% change	-2.26%	-3.99%	-4.22%	-3.46%	-3.41%	-3.64%	-3.34%	-3.21%	-3.38%	-3.43%
Domestic use										
Baseline	67,411	66,919	68,376	68,776	68,997	70,103	70,731	71,583	72,505	73,154
Scenario 1	67,466	67,189	68,703	69,120	69,253	70,371	71,068	71,894	72,814	73,513
% change	0.08%	0.40%	0.48%	0.50%	0.37%	0.38%	0.48%	0.43%	0.43%	0.49%
Trade *										
Baseline	6,109	5,621	5,557	5,761	5,823	5,935	6,100	6,192	6,277	6,409
Scenario 1	6,094	5,600	5,441	5,721	5,817	5,918	6,075	6,178	6,255	6,371
% change	-0.24%	-0.38%	-2.10%	-0.70%	-0.10%	-0.29%	-0.40%	-0.23%	-0.35%	-0.59%
Stocks-to-use ratio (Percent)										
Baseline	6.94	6.38	6.50	6.60	6.53	6.55	6.50	6.40	6.36	6.37
Scenario 1	6.76	6.08	6.18	6.32	6.27	6.27	6.24	6.15	6.10	6.11
% change	-2.50%	-4.64%	-4.96%	-4.19%	-4.00%	-4.26%	-4.03%	-3.85%	-4.03%	-4.14%

** Excludes intraregional trade*

Table B7. Soybean and product prices.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
					(US dollars per metric ton)					
					Soybean prices					
Illinois processor										
Baseline	398	378	386	399	388	395	405	406	409	412
Scenario 1	442	419	415	432	422	426	437	439	441	445
% change	11.18%	10.81%	7.37%	8.21%	8.81%	7.85%	7.83%	8.15%	7.94%	8.03%
CIF Rotterdam										
Baseline	511	486	496	511	497	505	517	518	521	523
Scenario 1	567	537	531	552	540	544	557	559	561	565
% change	10.94%	10.58%	7.22%	8.04%	8.63%	7.69%	7.67%	7.98%	7.78%	7.86%
					Soymeal prices					
FOB Decatur 48%										
Baseline	306.76	289.97	281.68	283.93	283.49	285.21	289.20	287.94	285.00	281.04
Scenario 1	336.88	317.19	303.02	307.20	308.00	309.09	313.86	313.51	310.80	307.64
% change	9.82%	9.39%	7.57%	8.20%	8.65%	8.37%	8.52%	8.88%	9.05%	9.47%
CIF Rotterdam										
Baseline	402.14	380.55	369.90	372.79	372.22	374.43	379.57	377.95	374.16	369.07
Scenario 1	440.80	415.53	397.33	402.71	403.73	405.13	411.26	410.81	407.33	403.27
% change	9.61%	9.19%	7.42%	8.03%	8.47%	8.20%	8.35%	8.69%	8.86%	9.27%
					Soy oil prices					
FOB Decatur										
Baseline	1,034	1,029	1,075	1,102	1,055	1,070	1,094	1,111	1,140	1,171
Scenario 1	1,084	1,092	1,125	1,164	1,125	1,139	1,168	1,190	1,221	1,254
% change	4.83%	6.13%	4.62%	5.60%	6.61%	6.45%	6.78%	7.16%	7.11%	7.11%
FOB Rotterdam										
Baseline	1,255	1,249	1,304	1,336	1,280	1,298	1,326	1,346	1,381	1,418
Scenario 1	1,314	1,324	1,363	1,409	1,363	1,380	1,414	1,441	1,477	1,516
% change	4.73%	6.01%	4.53%	5.49%	6.47%	6.31%	6.64%	7.01%	6.96%	6.97%

Table B8. Rapeseed and product prices.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
					(US dollars per metric ton)					
					Rapeseed prices					
Cash Vancouver										
Baseline	411.34	411.19	413.68	396.40	392.59	395.74	396.93	398.25	402.49	405.44
Scenario 1	426.09	427.14	428.47	412.66	409.56	412.84	415.11	417.33	422.15	425.98

Table B8. Rapeseed and product prices.

% change	3.58%	3.88%	3.58%	4.10%	4.32%	4.32%	4.58%	4.79%	4.89%	5.06%
CIF Hamburg										
Baseline	529.20	529.00	532.27	509.59	504.60	508.73	510.28	512.01	517.58	521.45
Scenario 1	548.56	549.94	551.70	530.93	526.85	531.16	534.14	537.06	543.39	548.41
% change	3.66%	3.96%	3.65%	4.19%	4.41%	4.41%	4.68%	4.89%	4.99%	5.17%
					Rapeseed meal price					
FOB Hamburg										
Baseline	303	301	295	294	301	305	308	309	308	304
Scenario 1	316	314	305	304	311	315	318	319	318	315
% change	4.32%	4.10%	3.57%	3.49%	3.34%	3.29%	3.28%	3.28%	3.37%	3.56%
					Rapeseed oil price					
FOB Hamburg										
Baseline	1,310	1,344	1,385	1,347	1,338	1,362	1,385	1,413	1,456	1,502
Scenario 1	1,345	1,384	1,423	1,391	1,385	1,409	1,436	1,467	1,512	1,560
% change	2.65%	2.98%	2.78%	3.22%	3.50%	3.48%	3.65%	3.81%	3.81%	3.83%

Table B9. Sunflower seed and product prices.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
CIF Lower Rhine					(US dollars per metric ton)					
Baseline	601	588	596	587	577	578	580	579	579	578
Scenario 1	617	610	614	606	596	596	599	598	598	598
% change	2.59%	3.73%	3.05%	3.13%	3.30%	3.16%	3.24%	3.32%	3.31%	3.40%
CIF Rotterdam										
Baseline	276	270	265	264	268	272	275	274	271	266
Scenario 1	285	280	274	272	276	280	282	282	279	275
% change	3.49%	3.76%	3.20%	3.04%	3.00%	2.93%	2.88%	2.89%	2.97%	3.13%
FOB NW Europe										
Baseline	1,432	1,424	1,463	1,471	1,467	1,490	1,517	1,545	1,577	1,609
Scenario 1	1,451	1,453	1,487	1,497	1,495	1,517	1,546	1,575	1,607	1,639
% change	1.35%	2.00%	1.63%	1.78%	1.92%	1.83%	1.88%	1.93%	1.90%	1.89%

Table B10. World soybean sector supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
					Soybeans					
Area harvested					(Thousand hectares)					
Baseline	96,946	99,931	100,256	100,770	102,729	103,231	103,792	105,049	105,939	106,803
Scenario 1	97,822	102,806	103,924	103,881	105,798	106,571	107,050	108,264	109,268	110,143
% change	0.90%	2.88%	3.66%	3.09%	2.99%	3.24%	3.14%	3.06%	3.14%	3.13%
Production					(Thousand metric tons)					
Baseline	242,217	252,279	255,277	258,491	266,315	270,217	274,164	280,326	285,531	290,682
Scenario 1	233,417	248,311	253,470	255,008	262,557	267,188	270,815	276,729	282,179	287,262
% change	-3.63%	-1.57%	-0.71%	-1.35%	-1.41%	-1.12%	-1.22%	-1.28%	-1.17%	-1.18%
Beginning stocks										
Baseline	47,227	48,060	49,742	50,129	49,637	50,547	50,748	50,506	50,755	50,910
Scenario 1	47,227	45,053	46,583	47,617	46,967	47,645	47,971	47,716	47,850	48,013
% change	0.00%	-6.26%	-6.35%	-5.01%	-5.38%	-5.74%	-5.47%	-5.52%	-5.72%	-5.69%
Domestic supply										

Table B10. World soybean sector supply and utilization.

Baseline	289,444	300,339	305,019	308,621	315,952	320,764	324,913	330,832	336,286	341,591
Scenario 1	280,643	293,364	300,052	302,625	309,524	314,833	318,785	324,445	330,029	335,275
% change	-3.04%	-2.32%	-1.63%	-1.94%	-2.03%	-1.85%	-1.89%	-1.93%	-1.86%	-1.85%
Crush										
Baseline	209,533	218,369	222,558	226,309	232,128	236,595	240,822	246,127	251,150	256,042
Scenario 1	204,327	214,881	220,184	223,155	228,795	233,559	237,612	242,789	247,905	252,748
% change	-2.48%	-1.60%	-1.07%	-1.39%	-1.44%	-1.28%	-1.33%	-1.36%	-1.29%	-1.29%
Food use										
Baseline	14,504	14,829	14,949	15,131	15,384	15,462	15,497	15,624	15,715	15,887
Scenario 1	14,182	14,484	14,723	14,900	15,112	15,218	15,257	15,366	15,468	15,637
% change	-2.22%	-2.33%	-1.51%	-1.53%	-1.77%	-1.58%	-1.55%	-1.65%	-1.58%	-1.57%
Other use										
Baseline	16,473	16,963	16,948	17,107	17,457	17,524	17,653	17,891	18,075	18,283
Scenario 1	16,224	16,981	17,093	17,167	17,537	17,651	17,765	18,004	18,208	18,409
% change	-1.51%	0.10%	0.85%	0.35%	0.45%	0.73%	0.64%	0.63%	0.74%	0.69%
Residual										
Baseline	436	436	436	436	436	436	436	436	436	436
Scenario 1	436	436	436	436	436	436	436	436	436	436
% change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ending stocks										
Baseline	48,060	49,742	50,129	49,637	50,547	50,748	50,506	50,755	50,910	50,943
Scenario 1	45,053	46,583	47,617	46,967	47,645	47,971	47,716	47,850	48,013	48,045
% change	-6.26%	-6.35%	-5.01%	-5.38%	-5.74%	-5.47%	-5.52%	-5.72%	-5.69%	-5.69%
Domestic use										
Baseline	289,006	300,339	305,020	308,621	315,952	320,765	324,913	330,832	336,286	341,592
Scenario 1	280,222	293,364	300,053	302,625	309,525	314,834	318,786	324,446	330,030	335,276
% change	-3.04%	-2.32%	-1.63%	-1.94%	-2.03%	-1.85%	-1.89%	-1.93%	-1.86%	-1.85%
Trade *										
Baseline	70,094	72,279	73,476	75,117	77,980	79,962	81,824	84,209	86,428	88,696
Scenario 1	68,359	71,000	73,071	74,718	77,695	80,052	82,051	84,462	86,814	89,144
% change	-2.48%	-1.77%	-0.55%	-0.53%	-0.36%	0.11%	0.28%	0.30%	0.45%	0.51%
					Soybean meal					
Production										
Baseline	165,122	172,092	175,401	178,363	182,958	186,486	189,825	194,015	197,983	201,848
Scenario 1	161,027	169,352	173,543	175,893	180,349	184,113	187,316	191,406	195,448	199,275
% change	-2.48%	-1.59%	-1.06%	-1.38%	-1.43%	-1.27%	-1.32%	-1.34%	-1.28%	-1.27%
Consumption										
Baseline	162,560	169,579	173,013	176,107	180,656	184,203	187,570	191,700	195,656	199,516
Scenario 1	158,877	166,793	171,072	173,657	178,056	181,814	185,063	189,095	193,116	196,945
% change	-2.27%	-1.64%	-1.12%	-1.39%	-1.44%	-1.30%	-1.34%	-1.36%	-1.30%	-1.29%
Ending stocks										
Baseline	5,768	6,069	6,243	6,286	6,374	6,445	6,487	6,588	6,702	6,822
Scenario 1	5,356	5,703	5,961	5,984	6,064	6,150	6,190	6,288	6,406	6,524
% change	-7.14%	-6.03%	-4.52%	-4.80%	-4.87%	-4.58%	-4.58%	-4.56%	-4.42%	-4.37%
Trade *										
Baseline	56,655	60,137	61,994	62,804	64,161	65,415	66,896	68,602	70,286	71,907

Table B10. World soybean sector supply and utilization.

Scenario 1	54,520	58,498	60,491	60,863	62,049	63,673	65,023	66,656	68,326	69,918
% change	-3.77%	-2.73%	-2.42%	-3.09%	-3.29%	-2.66%	-2.80%	-2.84%	-2.79%	-2.77%
					Soybean oil					
Production										
Baseline	39,020	40,765	41,647	42,446	43,638	44,587	45,498	46,618	47,694	48,753
Scenario 1	38,034	40,098	41,182	41,827	42,979	43,977	44,848	45,940	47,027	48,071
% change	-2.53%	-1.64%	-1.12%	-1.46%	-1.51%	-1.37%	-1.43%	-1.46%	-1.40%	-1.40%
Consumption										
Baseline	39,063	40,488	41,453	42,156	43,383	44,331	45,289	46,427	47,488	48,554
Scenario 1	38,171	39,841	40,965	41,562	42,735	43,719	44,649	45,754	46,821	47,875
% change	-2.28%	-1.60%	-1.18%	-1.41%	-1.49%	-1.38%	-1.41%	-1.45%	-1.40%	-1.40%
Ending stocks										
Baseline	2,361	2,422	2,400	2,473	2,512	2,552	2,545	2,521	2,511	2,494
Scenario 1	2,267	2,307	2,308	2,358	2,386	2,428	2,412	2,381	2,372	2,352
% change	-4.00%	-4.76%	-3.81%	-4.67%	-5.02%	-4.86%	-5.23%	-5.53%	-5.55%	-5.70%
Trade *										
Baseline	9,651	10,042	10,268	10,443	11,019	11,350	11,733	12,191	12,638	13,091
Scenario 1	9,458	9,708	9,938	10,027	10,525	10,814	11,153	11,581	12,011	12,456
% change	-2.00%	-3.33%	-3.21%	-3.99%	-4.48%	-4.72%	-4.95%	-5.00%	-4.96%	-4.85%
Per-capita consumption					**(Kilograms)**					
Baseline	5.78	5.92	6.00	6.03	6.14	6.20	6.27	6.36	6.44	6.51
Scenario 1	5.65	5.83	5.93	5.94	6.04	6.12	6.18	6.27	6.35	6.42
% change	-2.28%	-1.60%	-1.18%	-1.41%	-1.49%	-1.38%	-1.41%	-1.45%	-1.40%	-1.40%

** Excludes intraregional trade*

Table B11. World rapeseed sector supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
					Rapeseed					
Area harvested					**(Thousand hectares)**					
Baseline	28,729	29,388	29,904	30,355	30,612	30,935	31,345	31,743	32,145	32,587
Scenario 1	28,785	29,532	30,060	30,516	30,806	31,147	31,565	31,979	32,395	32,842
% change	0.19%	0.49%	0.52%	0.53%	0.63%	0.69%	0.70%	0.75%	0.78%	0.78%
Production					**(Thousand metric tons)**					
Baseline	50,085	51,784	53,205	54,597	55,648	56,797	58,087	59,356	60,642	62,001
Scenario 1	49,836	51,703	53,148	54,542	55,643	56,819	58,115	59,405	60,708	62,072
% change	-0.50%	-0.16%	-0.11%	-0.10%	-0.01%	0.04%	0.05%	0.08%	0.11%	0.11%
Beginning stocks										
Baseline	2,860	3,034	3,050	3,061	3,146	3,183	3,199	3,224	3,254	3,279
Scenario 1	2,860	2,975	2,987	3,005	3,084	3,120	3,136	3,159	3,187	3,212
% change	0.00%	-1.94%	-2.04%	-1.85%	-1.96%	-2.01%	-1.97%	-2.04%	-2.07%	-2.06%
Domestic supply										
Baseline	52,945	54,818	56,254	57,658	58,794	59,981	61,285	62,580	63,896	65,281
Scenario 1	52,696	54,678	56,135	57,546	58,727	59,938	61,251	62,564	63,895	65,284
% change	-0.47%	-0.25%	-0.21%	-0.19%	-0.11%	-0.07%	-0.06%	-0.03%	0.00%	0.00%
Crush										
Baseline	46,056	47,742	49,123	50,373	51,428	52,616	53,943	55,300	56,690	58,164

Table B11. World rapeseed sector supply and utilization.

Scenario 1	45,918	47,706	49,091	50,338	51,430	52,631	53,956	55,323	56,718	58,188
% change	-0.30%	-0.08%	-0.07%	-0.07%	0.00%	0.03%	0.02%	0.04%	0.05%	0.04%
Other use										
Baseline	3,584	3,755	3,799	3,868	3,912	3,895	3,846	3,755	3,656	3,537
Scenario 1	3,532	3,714	3,768	3,853	3,906	3,901	3,864	3,783	3,694	3,585
% change	-1.46%	-1.08%	-0.80%	-0.40%	-0.15%	0.14%	0.46%	0.76%	1.04%	1.35%
Residual										
Baseline	271	271	271	271	271	271	271	271	271	271
Scenario 1	271	271	271	271	271	271	271	271	271	271
% change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ending stocks										
Baseline	3,034	3,050	3,061	3,146	3,183	3,199	3,224	3,254	3,279	3,308
Scenario 1	2,975	2,987	3,005	3,084	3,120	3,136	3,159	3,187	3,212	3,239
% change	-1.94%	-2.04%	-1.85%	-1.96%	-2.01%	-1.97%	-2.04%	-2.07%	-2.06%	-2.07%
Domestic use										
Baseline	52,945	54,818	56,254	57,658	58,794	59,981	61,285	62,580	63,896	65,281
Scenario 1	52,696	54,678	56,135	57,546	58,727	59,938	61,251	62,564	63,895	65,284
% change	-0.47%	-0.25%	-0.21%	-0.19%	-0.11%	-0.07%	-0.06%	-0.03%	0.00%	0.00%
Trade *										
Baseline	7,472	8,088	8,304	8,493	8,675	8,868	9,086	9,330	9,591	9,866
Scenario 1	7,476	7,976	8,160	8,327	8,496	8,674	8,877	9,108	9,357	9,619
% change	0.05%	-1.39%	-1.74%	-1.96%	-2.06%	-2.18%	-2.30%	-2.38%	-2.44%	-2.50%
					Rapeseed meal					
Production										
Baseline	27,251	28,226	29,031	29,768	30,384	31,080	31,862	32,662	33,481	34,352
Scenario 1	27,170	28,203	29,011	29,745	30,383	31,087	31,866	32,672	33,494	34,362
% change	-0.30%	-0.08%	-0.07%	-0.08%	0.00%	0.02%	0.01%	0.03%	0.04%	0.03%
Consumption										
Baseline	27,559	28,537	29,340	30,081	30,703	31,397	32,177	32,976	33,793	34,662
Scenario 1	27,489	28,513	29,317	30,058	30,702	31,402	32,182	32,985	33,806	34,672
% change	-0.25%	-0.08%	-0.08%	-0.08%	0.00%	0.02%	0.01%	0.03%	0.04%	0.03%
Ending stocks										
Baseline	314	322	333	339	339	342	345	351	357	366
Scenario 1	303	312	324	330	331	334	338	343	350	358
% change	-3.72%	-3.34%	-2.70%	-2.54%	-2.43%	-2.34%	-2.28%	-2.19%	-2.14%	-2.13%
Trade *										
Baseline	2,404	2,738	2,946	3,008	3,121	3,214	3,291	3,369	3,446	3,626
Scenario 1	2,389	2,792	2,992	3,062	3,180	3,274	3,356	3,437	3,517	3,589
% change	-0.62%	1.95%	1.58%	1.82%	1.89%	1.88%	1.97%	2.02%	2.04%	-1.03%
					Rapeseed oil					
Production										
Baseline	18,068	18,760	19,321	19,821	20,250	20,731	21,265	21,809	22,367	22,957
Scenario 1	18,009	18,744	19,307	19,808	20,252	20,738	21,272	21,821	22,381	22,970
% change	-0.33%	-0.08%	-0.07%	-0.07%	0.01%	0.03%	0.03%	0.05%	0.06%	0.06%
Consumption										
Baseline	18,287	19,016	19,580	20,067	20,498	20,987	21,522	22,068	22,629	23,220

Table B11. World rapeseed sector supply and utilization.

Scenario 1	18,237	19,005	19,567	20,056	20,501	20,994	21,530	22,081	22,644	23,233
% change	-0.27%	-0.06%	-0.07%	-0.06%	0.02%	0.04%	0.04%	0.06%	0.06%	0.06%
Ending stocks										
Baseline	427	429	428	440	451	453	453	452	448	443
Scenario 1	418	416	414	424	433	435	434	433	428	422
% change	-2.18%	-3.13%	-3.24%	-3.58%	-3.86%	-3.95%	-4.14%	-4.35%	-4.49%	-4.63%
Trade *										
Baseline	1,591	1,631	1,708	1,759	1,830	1,909	1,981	2,045	2,101	2,158
Scenario 1	1,481	1,563	1,648	1,707	1,785	1,870	1,949	2,018	2,078	2,140
% change	-6.91%	-4.15%	-3.53%	-2.99%	-2.45%	-2.02%	-1.64%	-1.32%	-1.07%	-0.85%
Per-capita consumption					**(Kilograms)**					
Baseline	2.71	2.78	2.83	2.87	2.90	2.94	2.98	3.02	3.07	3.11
Scenario 1	2.70	2.78	2.83	2.87	2.90	2.94	2.98	3.02	3.07	3.12
% change	-0.27%	-0.06%	-0.07%	-0.06%	0.02%	0.04%	0.04%	0.06%	0.06%	0.06%

** Excludes intraregional trade*

Table B12. World sunflower sector supply and utilization.

	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
					Sunflower seed					
Area harvested					**(Thousand hectares)**					
Baseline	24,273	24,401	24,392	24,474	24,513	24,538	24,600	24,680	24,759	24,850
Scenario 1	24,261	24,392	24,404	24,490	24,537	24,571	24,633	24,717	24,800	24,891
% change	-0.05%	-0.04%	0.05%	0.07%	0.10%	0.13%	0.13%	0.15%	0.17%	0.16%
Production					**(Thousand metric tons)**					
Baseline	29,838	30,284	30,612	31,042	31,425	31,784	32,182	32,610	33,037	33,480
Scenario 1	29,828	30,287	30,642	31,074	31,469	31,841	32,241	32,675	33,108	33,552
% change	-0.04%	0.01%	0.10%	0.10%	0.14%	0.18%	0.18%	0.20%	0.22%	0.21%
Beginning stocks										
Baseline	1,884	2,032	2,089	2,105	2,136	2,179	2,198	2,215	2,238	2,258
Scenario 1	1,884	2,002	2,051	2,076	2,105	2,147	2,169	2,186	2,209	2,230
% change	0.00%	-1.50%	-1.81%	-1.38%	-1.43%	-1.44%	-1.29%	-1.29%	-1.28%	-1.22%
Domestic supply										
Baseline	31,722	32,316	32,701	33,147	33,561	33,962	34,380	34,825	35,275	35,737
Scenario 1	31,712	32,289	32,693	33,150	33,575	33,988	34,410	34,861	35,317	35,782
% change	-0.03%	-0.09%	-0.02%	0.01%	0.04%	0.08%	0.09%	0.10%	0.12%	0.12%
Crush										
Baseline	26,228	26,695	27,040	27,421	27,746	28,106	28,487	28,880	29,292	29,706
Scenario 1	26,276	26,738	27,084	27,480	27,817	28,181	28,567	28,967	29,381	29,797
% change	0.18%	0.16%	0.16%	0.21%	0.25%	0.27%	0.28%	0.30%	0.31%	0.31%
Other use										
Baseline	3,387	3,458	3,481	3,515	3,561	3,583	3,602	3,631	3,650	3,680
Scenario 1	3,359	3,425	3,458	3,490	3,536	3,562	3,581	3,610	3,631	3,661
% change	-0.84%	-0.96%	-0.66%	-0.72%	-0.72%	-0.59%	-0.59%	-0.58%	-0.53%	-0.52%
Residual										
Baseline	75	75	75	75	75	75	75	75	75	75
Scenario 1	75	75	75	75	75	75	75	75	75	75

Table B12. World sunflower sector supply and utilization.

% change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ending stocks										
Baseline	2,032	2,089	2,105	2,136	2,179	2,198	2,215	2,238	2,258	2,276
Scenario 1	2,002	2,051	2,076	2,105	2,147	2,169	2,186	2,209	2,230	2,249
% change	-1.50%	-1.81%	-1.38%	-1.43%	-1.44%	-1.29%	-1.29%	-1.28%	-1.22%	-1.21%
Domestic use										
Baseline	31,722	32,316	32,701	33,147	33,561	33,962	34,380	34,825	35,275	35,737
Scenario 1	31,712	32,289	32,693	33,150	33,575	33,988	34,410	34,861	35,317	35,782
% change	-0.03%	-0.09%	-0.02%	0.01%	0.04%	0.08%	0.09%	0.10%	0.12%	0.12%
Trade *										
Baseline	513	615	757	856	947	1,012	1,083	1,163	1,238	1,318
Scenario 1	511	577	708	811	905	972	1,043	1,125	1,200	1,280
% change	-0.33%	-6.18%	-6.50%	-5.30%	-4.47%	-3.98%	-3.71%	-3.33%	-3.09%	-2.94%
					Sunflower meal					
Production										
Baseline	11,614	11,806	11,958	12,129	12,268	12,419	12,579	12,745	12,918	13,092
Scenario 1	11,636	11,824	11,978	12,155	12,300	12,454	12,616	12,785	12,959	13,134
% change	0.18%	0.16%	0.16%	0.22%	0.26%	0.28%	0.29%	0.31%	0.32%	0.32%
Consumption										
Baseline	11,276	11,483	11,636	11,808	11,949	12,099	12,259	12,424	12,596	12,770
Scenario 1	11,301	11,502	11,655	11,834	11,981	12,134	12,296	12,464	12,638	12,813
% change	0.22%	0.16%	0.16%	0.22%	0.27%	0.28%	0.30%	0.32%	0.33%	0.33%
Ending stocks										
Baseline	257	262	266	268	270	272	274	277	280	284
Scenario 1	253	258	263	266	267	269	271	274	278	281
% change	-1.41%	-1.42%	-1.14%	-1.05%	-1.01%	-0.97%	-0.92%	-0.88%	-0.86%	-0.85%
Trade *										
Baseline	2,652	2,696	2,683	2,675	2,677	2,688	2,695	2,702	2,713	2,728
Scenario 1	2,655	2,699	2,685	2,677	2,680	2,691	2,698	2,705	2,716	2,731
% change	0.13%	0.09%	0.08%	0.11%	0.12%	0.11%	0.12%	0.12%	0.12%	0.12%
					Sunflower Oil					
Production										
Baseline	10,680	10,875	11,016	11,171	11,304	11,452	11,609	11,771	11,940	12,111
Scenario 1	10,700	10,893	11,034	11,195	11,333	11,483	11,642	11,807	11,977	12,149
% change	0.18%	0.16%	0.17%	0.22%	0.26%	0.27%	0.29%	0.30%	0.31%	0.31%
Consumption										
Baseline	10,294	10,518	10,673	10,823	10,950	11,105	11,262	11,424	11,594	11,766

Table B12. World sunflower sector supply and utilization.

Scenario 1	10,320	10,538	10,690	10,848	10,979	11,135	11,296	11,460	11,631	11,803
% change	0.25%	0.19%	0.15%	0.23%	0.27%	0.28%	0.30%	0.31%	0.32%	0.32%
Ending stocks										
Baseline	427	443	443	449	462	467	472	477	481	484
Scenario 1	421	434	436	441	453	459	464	469	473	476
% change	-1.57%	-2.03%	-1.59%	-1.75%	-1.82%	-1.68%	-1.70%	-1.72%	-1.66%	-1.63%
Trade *										
Baseline	3,236	3,349	3,396	3,446	3,516	3,600	3,685	3,774	3,869	3,972
Scenario 1	3,240	3,354	3,401	3,454	3,525	3,610	3,697	3,787	3,883	3,986
% change	0.13%	0.15%	0.17%	0.24%	0.26%	0.28%	0.31%	0.33%	0.34%	0.35%
Per-capita consumption					**(Kilograms)**					
Baseline	1.52	1.54	1.54	1.55	1.55	1.55	1.56	1.56	1.57	1.58
Scenario 1	1.53	1.54	1.55	1.55	1.55	1.56	1.56	1.57	1.58	1.58
% change	0.25%	0.19%	0.15%	0.23%	0.27%	0.28%	0.30%	0.31%	0.32%	0.32%

** Excludes intraregional trade*

Appendix C

Table C1. Baseline 2007-08 world production, consumption, and price data.

	Area (million hectares)	Production (million tonnes)	Trade (million tonnes)	Consumption (million tonnes)	Price ($/tonne)
Corn	159	790	97	777	218
Soybeans	91	218	78	n/a	469
Canola	28	48	4	n/a	644
Wheat	217	611	115	618	314
Barle	57	133	18	176	242
Sunflower	22	27	1	n/a	745
Sorghum	41	63	9	63	299
Soymeal	n/a	158	55	157	314
Soy oil	n/a	37	10	37	1,151
Rapemeal	n/a	27	4	27	298
Rape oil	n/a	18	2	18	1,410
Sun meal	n/a	11	3	10	191
Sun oil	n/a	10	3	9	1,639

Note: All values rounded to nearest million; n/a = not applicable

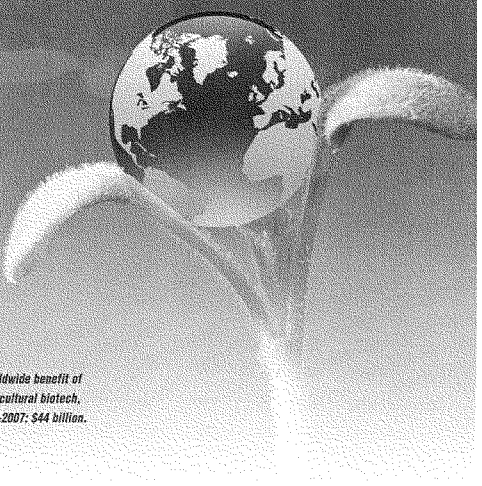
Facilitating Conservation Farming Practices and Enhancing Environmental Sustainability with Agricultural Biotechnology

EXECUTIVE SUMMARY

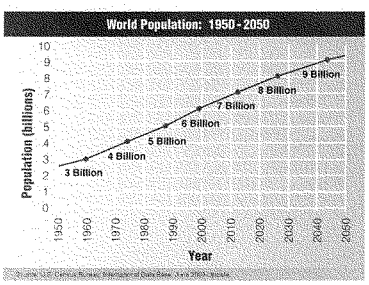
Today's farmers are under unprecedented pressure. The earth's population is nearly 7 billion, and is expected to reach 9 billion by 2050. Farmers must meet that growing demand – with a shrinking resource base – while protecting soil, air and water quality.

Nobel laureate Norman Borlaug, the father of the Green Revolution, summed up the challenge when he wrote that farmers and ranchers will be called upon to produce more food in the next 50 years than their ancestors did in the past 10,000 years – and do it in an environmentally sustainable manner.

Biotechnology-derived crops and the sustainable farming systems they facilitate are key tools in the race to grow more food, feed, fiber and fuel while protecting the environment.



Worldwide benefit of agricultural biotech, 1996-2007: $44 billion.

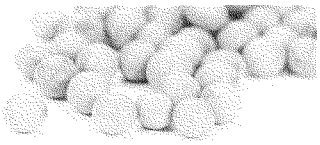


Race Against Time

To meet the projected soybean demand of 2030, growers would have to add 168 million acres of soybeans to existing production if global yields remained the same as today, or double those yields to 59.5 bushels per acre to harvest enough soybeans on today's acreage.

Biotech crops show promise to double or triple the current rate of yield increase in corn, and match or exceed the average 0.5-bushel-per-acre annual increase in soybean yields.

Not surprisingly, millions of farmers have adopted biotech crops readily. In the U.S., 91.5 percent of the soybeans, 85 percent of the corn and 88 percent of the cotton in the 2009 crop was planted to biotech varieties.



A New Generation

The first wave of biotechnology-derived crops focused primarily on input traits, which improved production efficiencies. In fact, the worldwide economic benefit of agricultural biotechnology between 1996 and 2007 was calculated at $44 billion.

The next generation of biotech crops will feature additional input traits such as tolerance to more herbicides and insects, as well as more efficient use of water and nitrogen. It will also introduce valuable output traits, including:

- Improved health profiles of oils and grains,
- Modification or elimination of major allergens, and
- More efficient conversion to biofuels.

Biotech means fewer applications. In 2007, U.S. farmers cut:
- ***47.4 million pounds of herbicide***
- ***8.67 million pounds of insecticide***

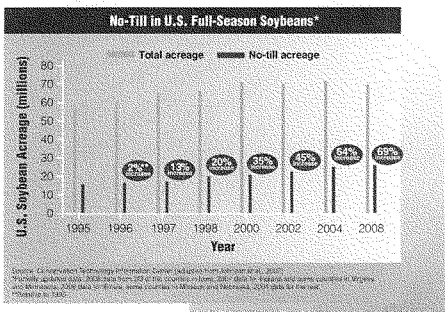
on acreage with biotech crops.

Protecting the Environment

Environmental benefits from biotech input traits add up quickly in pounds of herbicides and insecticides eliminated from the production system. For example:

- Herbicide-tolerant soybeans and cotton reduced U.S. herbicide usage in 2007 by 47.4 million pounds of active ingredient, and
- Insect-resistant cotton and corn varieties decreased insecticide applications that year by 8.67 million pounds of active ingredient.

There are significant long-term benefits, too. The adoption of biotech crops – especially soybeans – closely tracks the expansion of conservation tillage and no-till production. Between the introduction of Roundup Ready® soybeans in 1996 and the 2008 cropping season, the U.S. acreage of no-tilled full-season soybeans grew by nearly 70 percent.



Conservation tillage and no-till improve soil quality, conserve water and provide wildlife habitat. They also significantly reduce soil erosion, nutrient enrichment of streams and herbicide runoff. In fact, a number of studies show reductions in soil loss of more than 90 percent and reduced movement of total phosphorus by more than 70 percent on no-till fields.

High-residue farming practices also build up soil organic matter by capturing and storing atmospheric carbon. In fact, reducing tillage can quadruple carbon sequestration in cropland soils, and no-till can increase annual carbon storage five-fold. Reducing or eliminating tillage also lowers fuel consumption, cutting greenhouse gas emissions further. In all, conservation tillage and no-till can significantly improve the carbon footprint of farm operations.

Markets for water quality and carbon credits are emerging that could make environmental services such as combating water pollution and sequestering carbon – which conservation farming practices can often accomplish more cost-effectively than many alternatives – into income opportunities for farmers.

Best Option

No other options have been identified with the potential to improve yields and safeguard the environment as well as biotech crops farmed with sustainable practices.

Every ton of soil saved on the field, every pound of pesticide that doesn't have to be applied, every dollar that helps a farmer stay economically viable and every bushel of yield produced is a milestone in the effort to provide for a steadily increasing global population.

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Top 10 Benefits of Conservation Tillage



1 Reduces labor, saves time
As little as one trip for planting compared to two or more tillage operations means fewer hours on a tractor and fewer labor hours to pay ... or more acres to farm. For instance, on 500 acres the time savings can be as much as 225 hours per year. That's almost four 60-hour weeks.

2 Saves fuel
Save an average 3.5 gallons an acre or 1,750 gallons on a 500-acre farm.

3 Reduces machinery wear
Fewer trips save an estimated $5 per acre on machinery wear and maintenance costs—a $2,500 savings on a 500-acre farm.

4 Improves soil tilth
A continuous no-till system increases soil particle aggregation (small soil clumps) making it easier for plants to establish roots. Improved soil tilth also can minimize compaction. Of course, compaction is also reduced by reducing trips across the field.

5 Increases organic matter
The latest research shows the more soil is tilled, the more carbon is released to the air and the less carbon is available to build organic matter for future crops. In fact, carbon accounts for about half of organic matter.

6 Traps soil moisture to improve water availability
Keeping crop residue on the surface traps water in the soil by providing shade. The shade reduces water evaporation. In addition, residue acts as tiny dams slowing runoff and increasing the opportunity for water to soak into the soil. Another way infiltration increases is by the channels (macropores) created by earthworms and old plant roots. In fact, continuous no-till can result in as much as two additional inches of water available to plants in late summer.

7 Reduces soil erosion
Crop residues on the soil surface reduce erosion by water and wind. Depending on the amount of residues present, soil erosion can be reduced by up to 90% compared to an unprotected, intensively tilled field.

8 Improves water quality
Crop residue helps hold soil along with associated nutrients (particularly phosphorous) and pesticides on the field to reduce runoff into surface water. In fact, residue can cut herbicide runoff rates in half. Additionally, microbes that live in carbon-rich soils quickly degrade pesticides and utilize nutrients to protect groundwater quality.

9 Increases wildlife
Crop residues provide shelter and food for wildlife, such as game birds and small animals.

10 Improves air quality
Crop residue left on the surface improves air quality because it: Reduces wind erosion, thus it reduces the amount of dust in the air; Reduces fossil fuel emissions from tractors by making fewer trips across the field; and Reduces the release of carbon dioxide into the atmosphere by tying up more carbon in organic matter.

Source: Purdue University/Conservation Technology Information Center

Update on Increasing Crop Productivity

Increasing Crop Productivity to Meet Global Needs for Feed, Food, and Fuel

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Global demand and consumption of agricultural crops for food, feed, and fuel is increasing at a rapid pace. This demand for plant materials has been expanding for many years. However, recent increases in meat consumption in emerging economies together with accelerating use of grain for biofuel production in developed countries have placed new pressures on global grain supplies. To satisfy the growing, worldwide demand for grain, two broad options are available: (1) The area under production can be increased or (2) productivity can be improved on existing farmland. These two options are not mutually exclusive and both will be employed to produce the additional 200 million tonnes/year of corn (*Zea mays*) and wheat (*Triticum aestivum*) estimated to be needed by 2017. Both options will alter the environmental footprint of farming. Of the two options, increasing productivity on existing agricultural land is preferable as it avoids greenhouse gas emissions and the large-scale disruption of existing ecosystems associated with bringing new land into production. In the United States, breeders, agronomists, and farmers have a documented history of increasing yield. U.S. average corn yields have increased from approximately 1.6 tonnes/ha in the first third of the 20th century to today's approximately 9.5 tonnes/ha. This dramatic yield improvement is due to the development and widespread use of new farming technologies such as hybrid corn, synthetic fertilizers, and farm machinery. The introduction of biotechnology traits and development of new breeding methodology using DNA-based markers are further improving yields. Outside the United States, similar farming practices have been adopted in some agricultural nations, but in many major grain-producing countries, yields still lag well behind world averages. By continuing to develop new farming technologies and deploying of them on a global basis, demand for feed, fuel, and food can be met without the commitment of large land areas to new production.

Global demand for corn and wheat is growing at a rapid pace. As disposable incomes have risen in developing countries, meat consumption has increased. Among urban Chinese, meat consumption rose from 25 kg person^{-1} year^{-1} to 32 kg person^{-1} year^{-1} between 1996 and 2006 (von Braun, 2007). It is anticipated that meat consumption will continue to grow in developing countries because global consumption levels remain far below the approximately 100 kg person^{-1} year^{-1} meat consumption rate of the United States and many western European countries. Globally, meat consumption is expected to grow by 55 million tonnes to 310 million tonnes/year over the next decade (OECD-FAO, 2008). During this same period, biofuel production from corn and, to a lesser extent, wheat is expected to grow by 28 billion liters to 67 billion liters/year (Fig. 1). Meeting the expected demand for meat will require feed grain usage to increase by about 50 million tonnes to about 640 million tonnes/year. Concomitantly, grain consumption for biofuel production is likely to increase by about 60 million tonnes to about 145 million tonnes/year. When food use for corn and wheat is added to the calculation, total demand for corn and wheat over the next decade is expected to increase by about 15% or about 200 million tonnes/year to a total of approximately 1.5 billion tonnes/year (Table I; FAPRI, 2008).

The Food and Policy Research Institute (FAPRI) estimates that an additional 6 million ha of corn and 4 million ha of wheat plus a roughly 12% increase in global corn and wheat yields will be used to produce this additional 200 million tonnes of grain. Both increases in planted area and increases in yield are likely to be needed to meet global demand for grain. However, improving yield on existing agricultural land will have a lower environmental impact than bringing new land into production. Cultivation of new acreage requires land clearing and subsequent tillage that results in significant greenhouse gas emissions (Fargione et al., 2008) also has negative impacts upon biodiversity and water quality (Foley et al., 2005).

Increasing the productivity of existing agricultural land will also have environmental consequences (Tilman et al., 2002), but the negative consequences are generally less onerous and in some cases can be positive, depending upon how the land was previously used. Increased use of nitrogen fertilizers, a concern with both methods of increasing production, can increase nitrous oxide emissions, reduce water quality, and increase the size of hypoxic zones (Donner and Kucharik, 2008). However, incremental yield increases can be achieved on existing agricultural land through conservation tillage or transgenic insect control. Conservation tillage can decrease erosion, conserve soil

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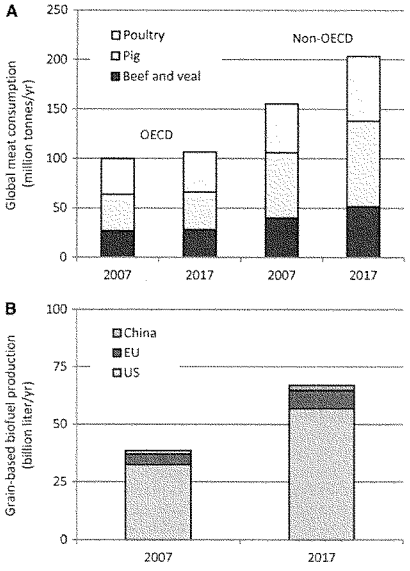


Figure 1. Estimates of global meat consumption and grain-based biofuel production. A, Global meat consumption estimates from OECD-FAO (2008). Meat consumption outside of the OECD is expected to increase by 48 million tonnes/year in the next decade. B, Global grain-based biofuel production estimates from FAPRI (2008). Grain-based biofuel production is expected to increase by 28 billion liters/year in the next decade.

moisture, and increase soil organic matter (Lal, 2004), and transgenic insect control can reduce broad spectrum insecticide use (Qaim and Zilberman, 2003; Cattaneo et al., 2006).

Global corn yields average 4.9 tonnes/ha and have been increasing steadily for many years (Fig. 2). This is encouraging, but yields in major grain-producing countries are nearly double the global average, suggesting that there is room for significant improvements in global yields. Average corn yield in the United States is 9.4 tonnes/ha and Canadian farmers attain average yields of 8.2 tonnes/ha with this crop of tropical origin. In contrast, corn yields in the 10 largest lower-yielding corn-producing countries are just 2.8 tonnes/ha (Table II; FAO, 2008), well below the global average. Much of the disparity in yields can be ascribed to agronomic practices, such as the use of open-pollinated corn varieties instead of hybrids, low input rates, or poor soil management. Brazil (29%), India (56%), and Romania (57%) all plant significant amounts of open-pollinated varieties. Weather is also a significant factor in some countries, but the use of less robust production systems can magnify the effects of unfavorable weather in countries such as South Africa and Romania. Increasing the use of modern farming practices in these countries, together with the infrastructure, marketing, and risk management tools needed to support them, could lead to significant increases in crop production that limit the need to bring incremental land into production.

Higher crop prices, prompted in part by rising demand, have increased costs for urban consumers, especially those in poorer countries. However, higher crop prices will also provide farmers with the economic incentive to invest in farming methods and technologies that improve crop yields (von Braun, 2007; Gallagher, 2008). Raising corn yields in the 10 largest, below average, corn-producing countries to just the world average will result in the production of an additional 100 million tonnes of corn or about 80% of the projected growth in demand by 2017. Implicit in this scenario is the idea that rising yields will markedly diminish the global need for new crop acreage.

Rates of gain for yield have changed as new agricultural technologies have been developed and adopted (Griliches, 1960; Troyer, 2006). Average annual corn grain yields in the United States were relatively steady at approximately 1.5 tonnes/ha prior to the 1930s. Yields began to increase when hybrid corn was first introduced and the rate of gain accelerated further in the 1950s as single cross hybrids were introduced

Table I. *Global corn and wheat production and consumption estimates from FAPRI's 2008 U.S. and World Agricultural Outlook*

All values are in million tonnes/year.

Crop	Crop Year	Production	Feed	Fuel	Food/Other
Corn	07/08	767	492	84	191
	17/18	896	528	143	225
	Increase	129	36	58	35
Wheat	07/08	603	98	1	503
	17/18	688	113	3	572
	Increase	85	14	2	68
Combined	07/08	1,370	590	85	694
	17/18	1,584	641	146	797
	Increase	214	50	60	103

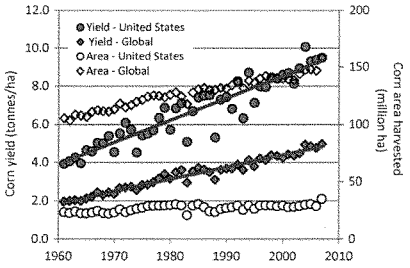


Figure 2. Annual corn yield averages and area planted in the United States and the world. Yield rate of gain in the United States from 1961 to 2007 was 0.11 tonnes ha^{-1} $year^{-1}$. Global yield rate of gain was about half of this at 0.06 tonnes ha^{-1} $year^{-1}$. Global corn area harvested has been increasing at the rate of 0.93 million ha/year. In the United States, corn area harvested increased by approximately 5 million ha in 2007 and 2008, although the long-term trend is much lower at 0.15 million ha/year (FAO, 2008). Lines indicate yield trend line.

(Troyer, 2006; Fig. 3A). Similarly, U.S. sorghum (*Sorghum bicolor*) yields increased sharply in the 1950s as hybrid sorghums were adopted (Miller and Kebede, 1984). Since that time, yield has improved steadily because of fertilizer management, the development of more efficient farm machinery, and the breeding of hybrids with improved stress tolerance that in turn enabled higher plant populations (Tollenaar and Lee, 2002) and earlier planting dates (Kucharik, 2008). Genetic gain experiments, in which hybrids that were widely grown at different points in time, often referred to as era hybrids, are compared side by side in the same trials, have been employed to estimate that about 50% of the yield gained between the introduction of hybrid corn, and today is derived from breeding and the remainder from improved agronomic practices (Duvick, 2005). Similar results have been reported from studies in France, Canada, and Brazil (Russell, 1991; Duvick, 2005). As new farming technologies are adopted by farmers, the gap between test plot results, such as those reported by Duvick, and on-farm yield averages decreases. Between 1935 and 1990 this gap shrank from about 3.0 tonnes/ha to about 1.8 tonnes/ha. However, as rates of gain derived from breeding have increased in recent years (Fig. 3B), this gap appears to have widened again. This observation supports the hypothesis that the immediate future will witness a shift in average rates of gain as newer hybrids are adopted more widely in the United States and elsewhere.

Marker-assisted breeding and biotechnology traits are relatively new technologies for the improvement of productivity. Incorporation of these technologies into crop improvement programs is likely to increase rates of gain beyond those seen in the last few decades. Results from a Monsanto Company study of a large number of commercial corn and soybean (*Glycine max*) populations indicated that use of markers can improve the rate of gain for yield and associated traits such as grain moisture and stalk lodging (Fig. 4; Eathington et al., 2007). Likewise, the suite of biotechnology traits currently used in commercial production in the United States increases average yields by protecting corn from the stress of competing pests and weeds (Fig. 5). Data

Table II. *Average corn yields from high- and low-yielding countries*

Values are 5-year averages from 2003 to 2007 (FAO, 2008). Yield, harvested area, and production were averaged independently and do not necessarily sum across this table.

Country	Area	Yield	Production
	million ha	*tonnes/ha*	*million tonnes*
High-yielding countries	64.4	7.5	482
United States	30.5	9.4	287
China	26.2	5.2	136
Argentina	2.5	6.8	17
France	1.6	8.4	14
Hungary	1.2	6.4	8
Canada	1.2	8.2	9
Italy	1.1	8.8	10
Low-yielding countries	48.0	2.8	132
Brazil	12.7	3.4	44
India	7.6	2.0	15
Mexico	7.4	2.9	21
Nigeria	3.8	1.6	6
Indonesia	3.4	3.4	12
Tanzania	2.9	1.1	3
South Africa	2.9	3.1	9
Romania	2.7	3.4	9
Philippines	2.5	2.2	6
Ukraine	1.9	3.7	7

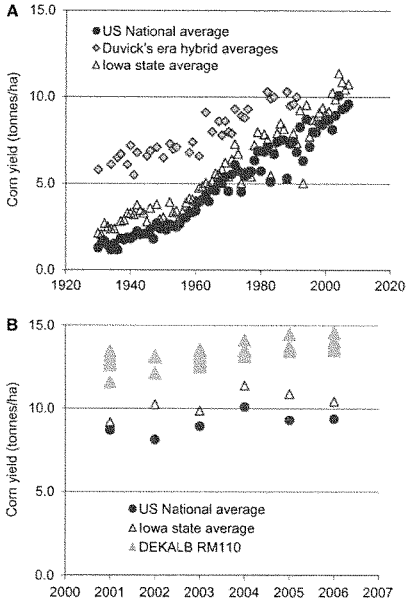


Figure 3. U.S. corn yield averages compared to yields obtained with widely used hybrids in test plots. A, National and Iowa corn yield averages (USDA ERS, 2008); Duvick's era hybrid average yields are from Duvick (1997). Iowa state averages are included as the era hybrid experiments were conducted in Iowa. The yield differential between test plots grown in Iowa and the Iowa state averages can be seen to decrease over time from approximately 3 tonnes/ha in 1936 to 1942 to approximately 1.8 tonnes/ha in 1988 to 1991. B, Genetic gain study of DEKALB commercial hybrids released from 2001 through 2006 in the 110-day relative maturity group (RM110), a region of the corn belt stretching across central Iowa. New RM110 commercial hybrids introduced from 2001 through 2006 were tested at 20 locations/year from 2005 through 2007 to produce the reported yield averages. All seed was from the same nursery and none of the hybrids contained biotechnology traits (Trevor Hohls, personal communication). Annual yield improvement was estimated at 0.24 tonnes ha^{-1} $year^{-1}$ for this group of hybrids and average yields were 3 tonnes/ha greater than Iowa and 4.2 tonnes/ha greater than the U.S. national average for this set of hybrids.

documenting the resulting reduction in risk to growers has been rigorously reviewed and acknowledged via the Federal Crop Insurance Corporation's Biotech Yield Endorsement, a risk management instrument that offers an insurance premium rate reduction for farmers using a suite of biotechnology traits (USDA FCIC, 2008). In 2008, farmers in the United States have planted 11 million ha of triple-stacked corn containing biotechnology traits that provide resistance to corn borers, corn rootworm, and the herbicide glyphosphate (Monsanto, 2008). While the yield benefits of these biotechnology traits vary from year to year, this level of planting will increase corn supply in the United States by approximately 5% if yield results seen in 2005 to 2007 are manifested in the 2008 growing season. The contribution of biotechnology traits to world corn supply will increase as they are used more widely.

The next generation of commercialized, biotechnology traits is likely to have a larger impact on crop yields. Improved drought tolerance will be one of the next major, transgenic technologies brought to the marketplace (Fig. 6; Nelson et al., 2007; Castiglioni et al., 2008). Drought tolerance has the potential to (1) increase yields in drier areas, (2) increase average yields in rain-fed systems by reducing the effects of sporadic drought, and (3) decrease water requirements in irrigated systems. Similarly, biotechnology traits that improve yield (Lundry et al., 2008) or oil concentration in soybean (Lardizabal et al., 2008) should improve global supplies of vegetable oil and protein meal. The first of these biotechnology traits, a higher-yielding, glyphosphate-tolerant soybean will be offered commercially in 2009 and commercialization of improved drought tolerance traits is expected around 2012. The transgenes described above are at relatively advanced stages of commercial development. A larger collection of transgenes derived from large-scale screening programs such as those described by Riechmann et al. (2000), Van Camp (2005), and Creelman et al. (2008) are at earlier stages of development. Biotechnology traits that improve grain yield and nitrogen use efficiency in replicated multiyear field trials are expected to reach farmers' fields in the second half of the next decade (Padgette, 2008).

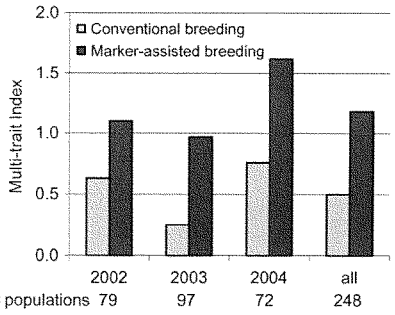


Figure 4. Breeding rates of gain for a multitrait index for 248 corn populations initiated across 3 years. The multitrait index is weighted toward yield, but also incorporates other agronomic traits such as grain moisture and stalk strength (Eathington et al., 2007).

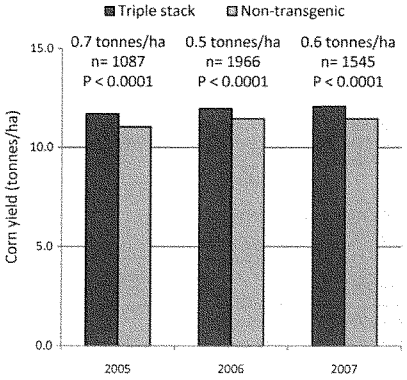


Figure 5. Yield advantage of triple-stack corn. Corn hybrids expressing either three biotechnology traits (YieldGard Plus with Roundup Ready Corn2 or YieldGard VT Triple) or without any biotechnology traits were tested in yield trials at the indicated number of locations across the United States in 2005, 2006, and 2007. Average yield values are shown in the bars and the yield difference between triple-stack and nontransgenic corn is indicated in the text above the bars. These are average values from yield trials run across corn-growing regions in the United States. Values can be significantly higher in regions with more insect pressure. Nontransgenic corn was treated with insecticide to control corn rootworm.

This group of genetically identified biotechnology traits are referred to as yield-enhancing traits, but the increase in yield may be due to an increase in yield potential and/or an improvement in tolerance to one or more stresses. Collectively, the next generation of biotechnology traits should contribute significantly to productivity on existing cropland, thereby increasing grain supplies and reduce the need to bring new land into production.

While breeders, agronomists, and farmers are working to increase yields, a number of factors that may reduce yields must be considered. Over the next two decades, climate change effects in the central United States are predicted to increase night air temperatures, the number and severity of adverse weather events, and increase the incidence of insect pests and disease. The result could be a drag on crop yields (Hatfield et al., 2008). Rapid adaptation of crops to changing climatic conditions may help mitigate these effects. Such rapid adaptation may occur for crops supported by strong breeding programs that continuously develop and introduce superior, locally adapted hybrids and varieties. New, higher-yielding hybrids produced from Monsanto's North American corn breeding program currently have a product half-life of approximately 4 years and are completely turned over about every 7 years, raising hopes that, for corn and possibly soybean, new varieties adapted to local conditions will be produced as a part of the ongoing breeding program. Unfortunately, this is not the case for crops such as wheat and rice (*Oryza sativa*) that lack the support of large, private breeding programs. Accordingly, increased public support for crop improvement efforts are sorely needed if new wheat and rice varieties are to be adapted to changing local climatic conditions. This is particularly true for regions of the world predicted to undergo more dramatic near term changes in climate than the central United States.

Nitrogen is another factor that may limit crop yields. Nitrogen may become less available as the cost of fertilizer rises and the continued growth of eutrophic dead zones and nitrous oxide emissions leads to changes in the way fertilizer is used (Donner and Kucharik, 2008). Nitrogen use efficiency, defined as the amount of crop produced per unit of input, has steadily improved in the United States since the 1980s (Frink et al., 1999). More precise nitrogen applications and genetic improvements in crops are likely to sustain improvements in nitrogen use efficiency although there is a limit to how far nitrogen application can be reduced. A 10 tonnes/ha corn crop contains around 100 kg nitrogen/ha as protein and at least this amount of nitrogen must be added back to the field to maintain fertility. Lastly, a sharp downturn in the global economy could restrict demand for both meat and fuel in ways that reduce the economic incentive to increase crop yields (IMF, 2008).

The combination of marker-assisted breeding, biotechnology traits, and continued advances in agro-

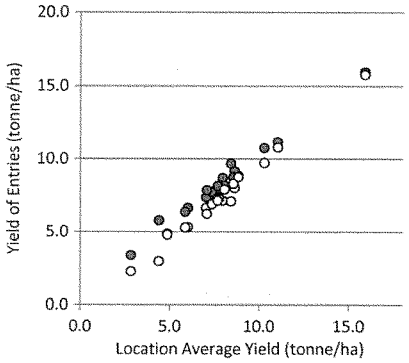


Figure 6. Yield increase in corn plants expressing cspB, a cold shock protein from *Bacillus subtilis*. Hybrids from a single transgenic event were tested in yield trials over 3 years at managed stress locations. Yield of the transgenic hybrid (green circles) and nontransgenic isogenic hybrids (white circles) at individual locations are plotted against the yield of all entries tested at that location (Castiglioni et al., 2008).

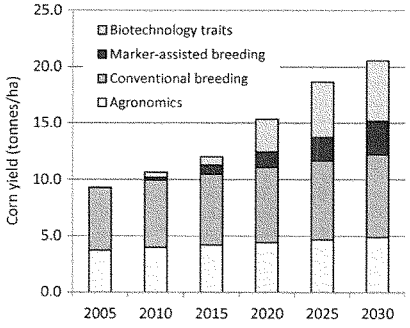


Figure 7. Anticipated impact of improvements in agronomics, breeding, and biotechnology on average corn yields in the United States. Rate of yield improvement due to breeding is extrapolated from observations such as those shown in Figure 3B, using data extending across maturity groups from Monsanto's North American corn breeding program. Agronomic (planting density, fertilizer use efficiency, improvements in soil management) contributions to the rate of yield improvement are considered to proceed at current historical rates based on estimates in Duvick (2005). Rate of yield improvement for biotechnology traits is a combination of the effects of current yield-protecting biotechnology traits, the introduction of biotechnology traits for drought tolerance, and additional yield-enhancing biotechnology traits. Biotechnology contributions to yield from herbicide tolerance, corn borer, and corn rootworm protection are estimated from the data presented in Figure 5. Biotechnology contributions to yield from drought tolerance are estimated from data presented in Figure 6 and an assumption that drought conditions strong enough to reduce yield will be seen on approximately 10% of the planted acres. Biotechnology contributions from yield-enhancing transgenes assume the introduction of three new biotechnology traits with effects similar to those described by Padgette (2008) over the course of the next decade. In each case biotechnology trait adoption curves such as those observed for current commercially available biotechnology traits are assumed (Monsanto, 2008).

nomic practices has the potential to double corn yields in the United States over the next two decades (Fig. 7). Doubling U.S. average yields would raise average yields to approximately 20 tonnes/ha, values now seen rarely in nonirrigated corn. The theoretical light-limited maximum for corn yields in the United States has been estimated at approximately 25 tonnes/ha (Specht et al., 1999; Tollenaar and Lee, 2002), close to the 24.2 tonnes/ha recorded on a 2-ha plot by David Hula of Charles City, Virginia in the 2007 National Corn Growers Association Corn Yield Contest. This fact suggests that corn yields can be doubled without large increases in yield potential, although significant improvements in broad stress tolerance, water use efficiency, and broad dissemination of excellent agronomic practices will be required to approach the Hula yield on broad acreage. Improving yields in corn and other crops on a global basis will allow farmers to meet global demand for feed, fuel, and food while minimizing the need to bring large amounts of new land into crop production. Even if crop producers supported by the agricultural sector fall short of doubling yields, continued public and private investment in agricultural technology will lead to significant increases in productivity that will help supply the world's needs for food, meat, and energy in a sustainable fashion.

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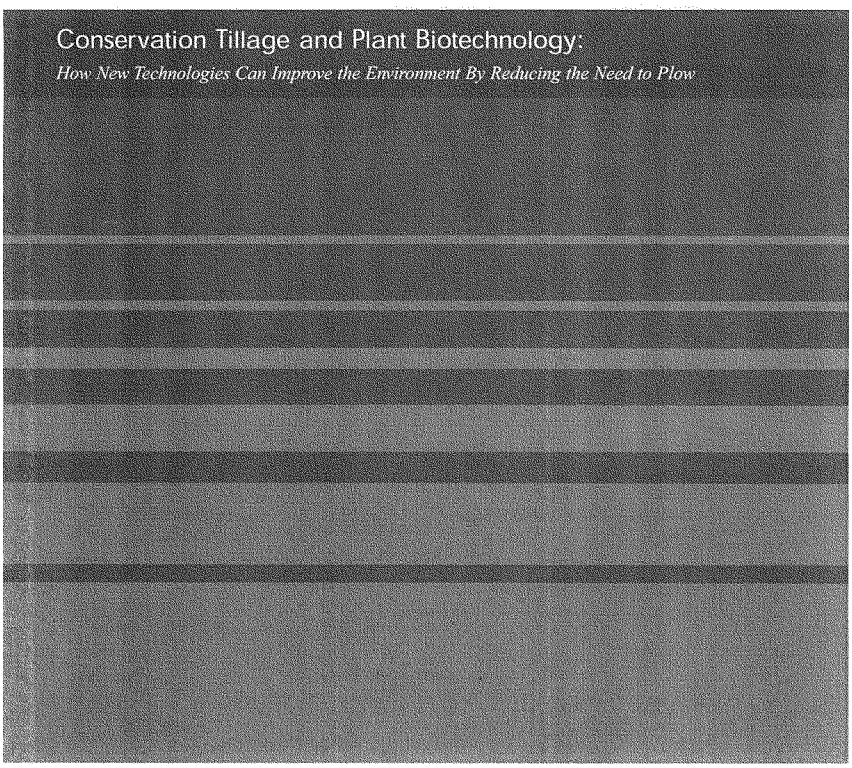
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Conservation Tillage and Plant Biotechnology:
How New Technologies Can Improve the Environment By Reducing the Need to Plow

By Richard Fawcett and Dan Towery

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Recreating the Prairie Soil Cycle

Two hundred years ago, most of the lands that today make up America's row-crop farms were vast expanses of grasslands or forests. These areas supported an ecological cycle that changed radically after settlers first put plows to the soil.

In the prairies, the annual cycle of grasses created a deep layer of litter, which protected the soil from wind and water erosion and temperature extremes. Soil organisms and insects thrived in the layers of dead grasses that built up each season. As prairie plants decayed, carbon and other nutrients returned to the soil. Water, instead of running off fields, seeped back into the soil, replenishing groundwater and nearby streams.

Nearly two centuries of intensive tillage later, that cycle has been radically altered. Organic matter has been lost, and erosion has taken topsoil. Within the past decade, however, many farmers have begun to recreate the cycle that once characterized the prairie soils and forests before they were cleared for farming. Corn, cotton, soybeans, wheat and other crops have replaced the tall grasses of the 18th century, which exist only in small pockets today. Nevertheless, the life cycle of the native soils is slowly returning as farmers convert their land to soil-saving conservation tillage while continuing to produce abundant crops.

Instead of plowing and disking their fields before planting, many farmers are leaving the residue of the previous crop on the soil surface. This layer of decaying plant material provides protective litter and begins to create conditions that existed before people first began to till the soil.

Conservation Tillage Benefits the Environment

Conservation tillage, as defined by the Conservation Technology Information Center, (www.ctic.purdue.edu) means any minimal tillage system that leaves the soil surface at least 30 percent covered by crop residue. Farmers employ various conservation tillage systems, which leave various amounts of residue. No-till, in which the soil is left undisturbed by tillage and the residue is left on the soil surface, is the most effective soil-conserving system. Research shows that land left in continuous no-till can eventually create a soil, water and biological system that more closely resembles characteristics of native soils before the advent of agriculture. No-till systems also can provide cover for wildlife if the stubble from the previous crop is left standing. Other studies show that reducing tillage can produce many other environmental benefits, such as:

- Reduced soil erosion.
- Improved moisture content in soil.
- Healthier, more nutrient-enriched soil.
- More earthworms and beneficial soil microbes.
- Reduced consumption of fuel to operate equipment.
- The return of beneficial insects, birds and other wildlife in and around fields.
- Less sediment and chemical runoff entering streams.
- Reduced potential for flooding.
- Less dust and smoke to pollute the air.
- Less carbon dioxide released into the atmosphere.

Biotechnology and the Growth of No-Till

The movement toward leaving more crop residue on farm fields expanded rapidly in the early 1990s. The federal government largely drove this by requiring soil conservation efforts on highly erodible acres in order to participate in farm programs. The introduction of improved high-residue seeding equipment and improved weed control technology also aided adoption.

The conversion of acreage to conservation tillage began to level off somewhat by the mid-1990s. However, since the mid-1990s, farmers have been increasing the amount of residue left on the soil surface. While reduced tillage practices such as mulch-till and ridge-till have been fairly static, farmers have been moving toward no-till farming. This agricultural practice, which has the potential to most closely approximate the native soil cycle, has expanded steadily during the time period when herbicide-tolerant crops, developed through biotechnology, have been adopted by U.S. and Canadian farmers.

There is a strong association between the use of herbicide-tolerant biotech crops and recent improvements in tillage reduction. Four trends support this conclusion:

- Weed control is a major consideration when farmers are weighing whether to implement conservation tillage, and several surveys indicate that farmers have more confidence in weed control since the introduction of herbicide-tolerant biotech crops. In some surveys, farmers say herbicide-tolerant crops enabled them to increase the amount of residue they leave on their fields.

- No-till, the tillage system that most relies on good herbicide performance, has grown more than other reduced tillage systems since 1996, and nearly all the growth has occurred in crops where herbicide-tolerance technology is available – soybeans, cotton and canola. (Herbicide-tolerant corn has not been widely adopted due to pending regulatory approval in Europe, nor has no-till corn expanded as rapidly as other crops.)
- Farmers who purchase herbicide-tolerant seeds use them disproportionately on their conservation tillage acres.
- Farmers who do not purchase herbicide-tolerant seeds are not as likely to participate in conservation tillage.

The main reason farmers till their soil is to control weeds, which compete with their crops for space, nutrients and water and can interfere with harvesting equipment. Historically, farmers have plowed under emerged weeds before planting and tilled the soil in preparation for herbicides that prevent additional weeds from emerging. If herbicides failed due to weather conditions, farmers could use additional tillage as a rescue.

With herbicide-tolerant crops, farmers allow weeds to emerge with their crops. Then they apply herbicide over the top of their crop, removing the weeds without harming the crop, which has been modified through biotechnology to withstand the herbicide. This improvement in weed control gives increased confidence that weeds can be controlled economically without relying on tillage. It partially explains why no-till farming has been increasing significantly in crops where the technology is available.

Many analyses have shown that conservation tillage provides economic benefits by saving time and reducing fuel and equipment costs. Despite these benefits, many farmers were reluctant to commit to a new system in which they saw potential risk of yield reduction due to competition from weeds. The trends since 1996, when herbicide-tolerant crops were first introduced, provide a strong indication that improved weed control made possible with the new biotech crops has given growers the confidence to increase their use of conservation tillage, especially no-till.

WHAT IS CONSERVATION TILLAGE?

Crop residues left on the soil surface protect the soil from the energy of wind and raindrops. Research shows that reductions in erosion are proportional to the degree that the soil surface is covered by crop residue.[2]

The Conservation Technology Information Center (CTIC) has defined various tillage systems according to how much crop residue is left on the soil surface and types of tillage tools used.

Conservation tillage – Any tillage and planting system that covers more than 30 percent of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. No-till, ridge-till, and mulch-till are types of conservation tillage.

No-till – The soil is left undisturbed from harvest to planting except for planting and nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slots created by coulters, row cleaners, disk openers, in-row chisels or rotary tillers. Weed control is accomplished primarily by herbicides. Cultivation may be used for emergency weed control.

Ridge-till – The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters or row cleaners. Residue is left on the surface between the ridges. Weed control is accomplished with herbicides and/or mechanical cultivation. Ridges are rebuilt during cultivation.



The residue from the previous year's crop remains on the surface of this no-till soybean field, protecting the soil from water and wind erosion.

Mulch-till – The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, and blades are used. Weed control is accomplished with herbicides and/or mechanical cultivation.

Conventional-tillage leaves less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. It typically involves plowing or intensive tillage. Tillage types that leave 15 to 30 percent residue cover after planting or 500 to 1,000 pounds per acre of small grain residue sometimes are referred to as **reduced tillage**, but they do not qualify as **conservation tillage.**



As a significant percentage of agriculture is left untilled, more like the original prairies, the water and soil cycles also will begin to return to a more natural state. Continued adoption of no-till practices will bring additional environmental benefits, which include increasing the amount of topsoil that is saved each year, reducing runoff into streams and further cutting back on fuel use and emissions.

Improved weed control available through herbicide-tolerant crops will be an important factor in continued adoption of no-till.

Tillage was once necessary

Repeated tillage to prepare crop seedbeds and control weeds was an indispensable component of agriculture until the last half of the 20th century. However, excessive tillage causes soil erosion, thus reducing the sustainability of agriculture. For example, 100 years after Iowa was settled, nearly half the original topsoil had eroded.[1] Repeated tillage also can reduce soil quality and productivity by destroying soil structure, reducing organic matter content and harming beneficial invertebrates such as earthworms. Sediment eroded from intensively tilled fields fouls aquatic systems, and runoff of water contributes to flooding. Tillage destroys wildlife food sources and reduces surface crop residues that serve as wildlife cover.

Edward Faulkner was one of the earliest proponents of eliminating the use of the moldboard plow, the most widely used primary tillage tool until the late 20th century. In his 1943 book, "Plowman's Folly,"[2] he called the plow "the villain in the world's agricultural drama." He concluded that plowing crop residues deep into the soil, leaving the soil's surface bare, reduced the long-term productivity of the soil. Faulkner wrote: "Had we not originally gone contrary to the laws of nature by plowing the land, we would have avoided the problems … the erosion, the sour soils, the mounting floods, the lowering water table, the vanishing wildlife, the compact and impervious soil surfaces."

Although many of Faulkner's predictions of benefits from what was later to be called "conservation tillage" turned out to be true, poor weed control, experienced when tillage was reduced, prevented most farmers from adopting the systems until the introduction of herbicides. Development of effective herbicides in the 1960s allowed farmers to reduce their dependence on repeated tillage to control weeds. Some eliminated tillage altogether.

However, weed control challenges and uncertainties remain. Some problem weeds, such as perennials, remain difficult to control. A few weeds have developed resistance to some popular herbicides. Because most herbicides do not control all weed species present in fields, farmers often apply two, three or more herbicides in combination. Effective weed control with herbicides requires careful identification of weed species and precise application timing. Crop injury may occur if adverse weather conditions reduce crop tolerance, or herbicide residues in the soil injure rotational crops. Soil-applied herbicides may fail if sufficient rainfall does not occur to activate the chemical.

Biotechnology has given farmers additional weed control options by facilitating the development of crop varieties tolerant to herbicides, such as glyphosate and glufosinate. These herbicides, rather than preventing weed growth in the soil, are applied to emerged weeds and are effective against a broad spectrum of annual and perennial weeds. They are well-suited to conservation tillage systems because they do not require incorporation with tillage tools. In addition, they are applied at low rates, have low toxicity to animals and degrade rapidly. They cannot, however, be used with crops that have not been made tolerant through biotechnology, because they would have the same detrimental effect on the crop as they have on weeds.

As will be discussed later, farmers are using herbicide-tolerant crops disproportionately in reduced tillage systems, especially no-till. The majority of such crops are glyphosate-tolerant; therefore, subsequent discussion of herbicide-tolerant crops in this report will focus on glyphosate-tolerant varieties developed through biotechnology.

ENVIRONMENTAL BENEFITS OF CONSERVATION TILLAGE

As no-till acreage expands, farmers are able to recreate soil and water cycles more closely resembling characteristics of prairies and woodlands before settlers first put plows to the soil. The residue from the harvested crop is left on the soil surface. This layer of leaves and stems mimics the layer of litter that once covered native soils, protecting the soil from heat, preserving soil moisture and preventing erosion. Decaying root channels and burrows from earthworms serve as macropores, which aerate the soil and improve water infiltration. Other attendant benefits, including a return of soil organisms, birds and mammals, also are being realized.

Erosion is reduced by nearly 1 billion tons per year

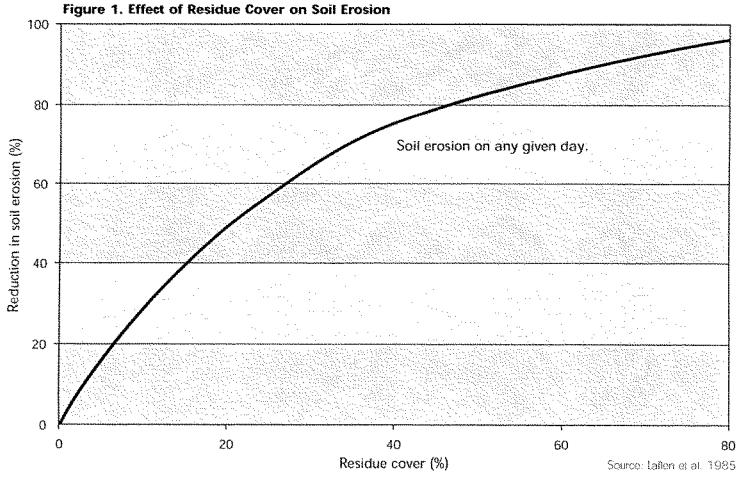
Conservation tillage is one of the most practical and economical ways to reduce soil erosion. Reducing or eliminating tillage operations leaves more crop residue on the soil surface, protecting the soil from the erosive impacts of wind and rain. Reductions in erosion are proportional to the amount of soil covered by crop residue (Figure 1).[3]

No-till systems, which leave nearly all plant surface residue in place, can reduce erosion by 90 percent or more.[4,5] The 1997 National Resources Inventory[6] showed that dramatic decreases in erosion have taken place in the United States since 1982. Much of this reduction can be credited to the adoption of conservation tillage by U.S. farmers. Sheet and rill (water) erosion on cultivated cropland fell from an average 4.4 tons per acre per year (9,856 kg/ha/year) in 1982 to 3.1 tons/acre/year (6,944 kg/ha/year) in 1997, a 30 percent decrease (Figure 2). The average wind erosion rate dropped 31 percent. Almost 1 billion tons per year of soil savings have occurred due to these changes in management. However, erosion is still occurring at a rate of 1.9 billion tons per year, and 108 million acres (29 percent of cropland) is still eroding at excessive rates.[7]

$3.5 billion in sedimentation costs saved in 2002

The 1998 National Water Quality Inventory reports that sedimentation is the most prevalent pollutant in streams that have been identified as environmentally impaired.[8] Unacceptable levels of sediment occur in 40 percent of impaired stream miles. Bacteria were the second most prevalent pollutant, present in 38 percent of impaired miles, followed by nutrients, occurring in 30 percent of impaired miles. Conservation tillage reduces the runoff of all these pollutants to surface water systems.

Figure 1. Effect of Residue Cover on Soil Erosion



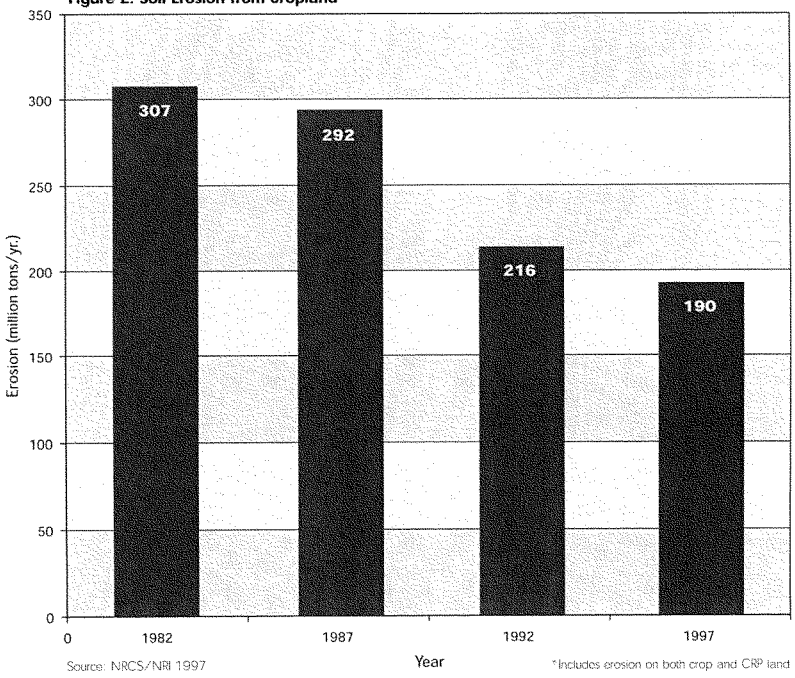
Sediment decreases the storage capacity of reservoirs and interferes with the navigational and recreational uses of water. According to a U.S. Department of Agriculture study, the annual cost of damage to water quality from sediment originating on farmers' fields was $4 billion to $5 billion in the mid-1980s.[6]

Table 1 shows USDA estimates of the annual offsite damage from water and wind erosion. These damage values were calculated considering the cost of maintenance due to erosion, such as dredging rivers, cleaning road ditches and treating drinking water, as well as economic losses. Soil erosion rates fell 30 percent between 1982 and 1997, largely due to the adoption of conservation tillage by U.S. farmers and land enrolled in the Conservation Reserve Program (CRP).[6] The offsite erosion damages ($8.78 billion) shown in Table 1 were calculated in the 1980s. If offsite damages are proportional to erosion rates, an estimated $2.6 billion annual savings has resulted due

Table 1: Annual Offsite Damage from Soil Erosion in the United States

Damage Category	Annual Offsite Damage (Millions of $)
Water recreation	2,679
Water storage	1,090
Navigation	749
Flooding	978
Ditches	978
Commercial fishing	450
Municipal water treatment	964
Municipal and industrial use	1,196
Steam power cooling	24
TOTAL	$8,783

Figure 2. Soil Erosion from Cropland*



Source: NRCS/NRI 1997

*Includes erosion on both crop and CRP land

to the erosion reduction achieved by farmers largely through conservation tillage. If adjusted for inflation this would represent a $3.5 billion annual savings in 2002.

Sediment in water also has human health implications. Sediment and organic carbon carried on sediment cause problems for water utilities that use surface water as a drinking water source. Chlorine used to disinfect water reacts with organic carbon to produce trihalomethanes such as chloroform. Due to carcinogenicity, trihalomethanes are regulated under the Safe Drinking Water Act. Additional filtering is required to reduce sediment and organic carbon to prevent trihalomethane formation. Allowed levels of trihalomethanes are scheduled to decrease in the future, which will increase costs to water utilities.

Insects, earthworms and microbes thrive

Stinner and House[10] have reviewed studies of arthropods and invertebrates in no-till and other conservation tillage systems. They found that no-till crop fields generally have increased diversity of surface microarthropods. Many beneficial predatory arthropods, including ground beetles and spiders, are increased by no-till. For example, House and Parmalee[11] found 17.6 carabid beetles per square meter in no-till soybeans compared with 0.38 per square meter in plowed treatments. Carabid beetles are important predators of pests in many crops. Mites, which are important predators of other arthropods and nematodes, are increased in no-till.[12] Increased diversity of arthropods with no-till has been attributed to the increased structural diversity of litter.

Earthworm populations have consistently increased as tillage is reduced. House and Parmalee[11] compared a field with 17 years of no-till cropping with a conventionally tilled field and found from 3.5 to 6.3 times more earthworms in the no-till field. Earth-worms help incorporate organic residues into the soil, aerate the soil and improve water infiltration. Night crawlers (*Lumbricus terrestris* L.) are large, surface-feeding earthworms, which live in permanent, vertical burrows. Tillage harms earthworms by burying food sources and destroying burrows. As many as 81,000 burrows per acre (200,000/ha) have been reported in no-till fields.[13] Improvements in water infiltration, which often accompany conversion to no-till, have been at least partly attributed to these burrows.[14]

Tillage, which incorporates organic debris into the soil, is more suitable for microorganisms with higher turnover rates, such as bacteria and bactivorous fauna, including protozoa and nematodes.[15,16] Decomposition processes in no-tillage systems are controlled primarily by fungi, with fungivorous microarthropods, nematodes and earthworms dominant in subsequent steps in the food web.[17] Fungal dominated microbial communities of no-till systems store more organic material for longer periods, resulting in higher steady-state levels of organic matter. Fungal hyphae aid in the formation of soil aggregates or tiny soil particles bound into larger units. These aggregates aid in improving soil structure and increasing retention of soil carbon. Extracellular polysaccharides of fungi also are important in the formation of soil aggregates. Soil aggregates allow for the most desirable mix of air and water for good plant growth.

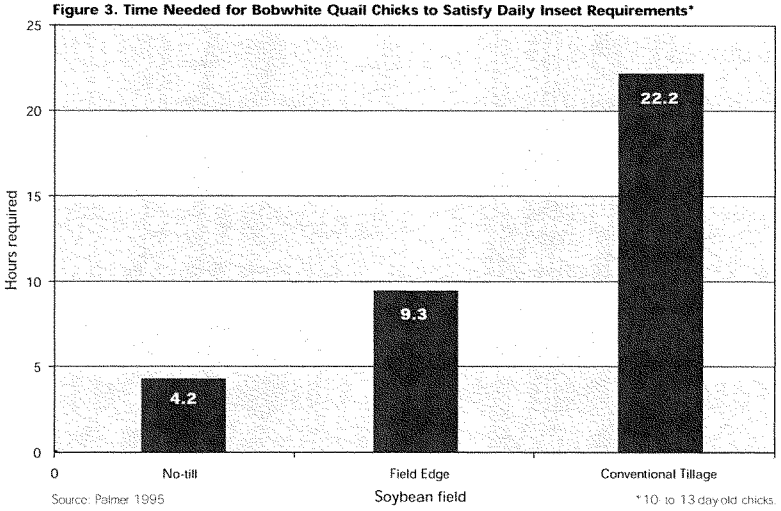
Total microbial populations are often higher in no-till soils than in tilled soils. Doran[18] found that counts of aerobic microorganisms, facultative anaerobes and denitrifiers in the surface of no-till soils were higher than in the surface of plowed soil. Phosphatase and dehydrogenase enzyme activities and contents of water and organic carbon and nitrogen in the surface of no-till soil also were significantly higher than those for conventional tillage. Such increases in microbial activity have been associated with increased rates of herbicide and insecticide degradation with no-till.[18,19] Rapid degradation of pesticides is one of the factors that reduce their potential to enter surface or ground-water supplies.

Habitat for birds and mammals improves

Research shows that no-till fields provide food and habitat for birds and mammals. Insects and other arthropods, which thrive in the protective residue in no-till fields, are important food sources for many birds. Palmer[20] studied bobwhite quail (*Colinus virginianus*) behavior in no-till and conventional fields in North Carolina. The research showed that quail chicks needed 22 hours to obtain their minimum daily requirement of insects in conventional soybean fields. In no-till soybean fields, only 4.2 hours were required to obtain the minimum daily requirement, about the same as the 4.3 hours required in natural fallow areas believed to be ideal quail habitat (Figure 3).

Cover provided by crop residue, plus waste grain and weed seed food sources left on the soil surface, along with less disturbance from field operations, are all beneficial to wildlife. Many studies have shown that no-till row crop fields have higher densities of birds and nests and are used by a greater variety of bird species during the breeding season than tilled fields.[21,22] Bird nesting success in conventionally tilled row-crop

Figure 3. Time Needed for Bobwhite Quail Chicks to Satisfy Daily Insect Requirements*



Source: Palmer 1995

*10- to 13-day-old chicks.

fields is usually below levels needed to sustain populations, often because field operations disrupt nests.[23] As fewer trips over the field with equipment are made with conservation tillage, nesting is favored, particularly for species that normally raise only one brood per year, such as the ringneck pheasant. Grassy nesting cover adjacent to no-till fields provides even more favorable habitat.

Small mammals also favor conservation tillage. In Illinois, no-till cornfields had more abundant and more diverse invertebrates, birds and small mammals than conventionally tilled corn.[22] Small-mammal populations, particularly deer mice, were more stable in no-till. Management changes can further improve wildlife habitat provided by no-till fields. Leaving stubble 10 to 14 inches tall when harvesting small grains provides improved habitat compared with shorter stubble heights. Additional research is needed to determine how to maximize the wildlife benefits of conservation tillage.

Preventing sediment and nutrient loss improves aquatic habitat

Sediment in rivers, streams and lakes covers gravel beds needed for habitat by fish and crustaceans. Sediment also clouds water, reducing sunlight penetration and reducing photosynthesis of submerged plants and algae, causing a cascading effect through food chains. Conservation tillage's ability to dramatically reduce erosion reduces delivery of sediment to aquatic systems, improving aquatic habitats.

Excessive loads of the nutrients phosphorus and nitrogen from agricultural land and other sources can lead to excessive growth of aquatic plants. When these plants decompose, oxygen concentrations in water can drop to levels too low to support some aquatic organisms, a condition called hypoxia. Hypoxia can occur in fresh water bodies or marine environments such as the Gulf of Mexico.[24] Because conservation tillage reduces nutrient losses, it is an important tool in reducing agriculture's impact on hypoxia.

Runoff into streams is reduced

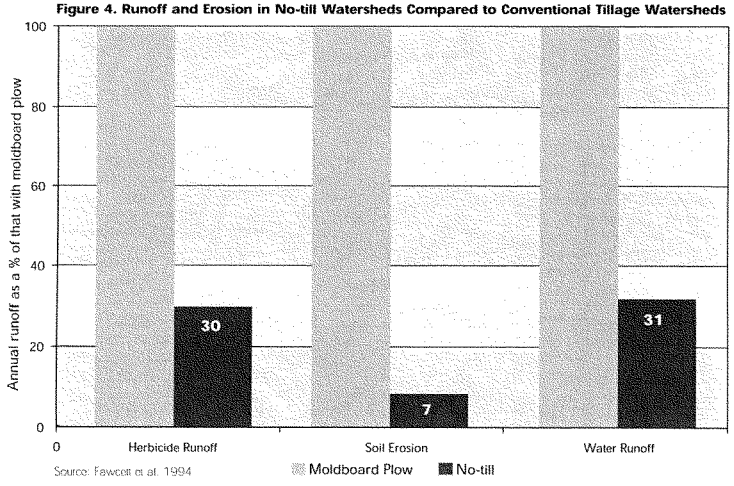
As portions of agriculture are returned to an untilled state more like the original prairies and forests, the water cycle also will return to a more natural state.[25] With less water runoff and more infiltration, streams are fed more by subsurface flow than surface runoff. This allows better use of water and nutrients by crops and allows soil clay, organic matter and biological activity to filter the water before it becomes surface water.

Decreased runoff means that fewer pollutants enter streams. Several paired watershed studies showed that no-till fields produced no seasonal runoff while conventional tillage watersheds had significant water runoff, soil erosion and pesticide runoff.[26, 27, 28] An Ohio study compared total water runoff from a 1.2-acre (0.5 ha) watershed with 9 percent slope that had been farmed for 20 years in continuous no-till corn to a similar conventionally tilled watershed. Over four years, runoff was 99 percent less under the long-term no-till. This decrease in runoff was attributed to increases in infiltration due to development of soil macropores in the absence of tillage.[29] Cracks, root channels and earthworm holes allow water to bypass upper soil layers when rainfall exceeds the capacity of soil to absorb water through capillary flow, the movement through tiny spaces between soil particles.[14]

When runoff is reduced, the flow of pollutants such as sediment, fertilizers and pesticides also is reduced. Pesticides and fertilizers enter surface waters in liquid solution or attached to sediment that washes off farm fields. Studies have demonstrated how no-till reduces chemical runoff. Baker and Laflen[30] found that a 97 percent reduction in sediment loss for no-till (relative to the moldboard plow) resulted in a 75 to 90 percent reduction in total nitrogen loss for soybeans planted following corn and 50 to 73 percent reduction in nitrogen loss for corn following soybeans. Studies show reduction in phosphorus fertilizer runoff if the fertilizers are subsurface band-applied instead of surface-applied. Andraski *et al.*[31] compared runoff losses of phosphate from four tillage systems when fertilizer was subsurface banded in all systems. Three reduced tillage systems — no-till, mulch-till and strip-till — reduced total phosphate losses by 81, 70 and 59 percent respectively, compared with the moldboard plow. Soluble phosphorus losses also were reduced by no-till and mulch-till, which employs a chisel plow. When total phosphorus losses were compared in no-till and conventional tillage, a 97 percent reduction in soil erosion with no-till resulted in an 80 to 91 percent reduction in phosphorus loss[30] for soybeans following corn. For corn following soybeans, an 86 percent reduction in soil loss led to a 66 to 77 percent reduction in phosphorus lost.[30]

Runoff of pesticides, both soil-attached and dissolved, usually is reduced in conservation tillage. No-till sometimes has resulted in complete elimination of pesticide runoff.[26, 27, 28] A summary of published natural rainfall studies comparing no-till with moldboard plowing showed that, on the average (over 32 treatment-site-years of data), no-till resulted in 70 percent less herbicide runoff, 93 percent less erosion and 69 percent less water runoff than moldboard plowing (Figure 4).[32]

Figure 4. Runoff and Erosion in No-till Watersheds Compared to Conventional Tillage Watersheds



Source: Fawcett et al. 1994

Other conservation tillage systems also have reduced herbicide runoff. In a Kentucky natural rainfall study, both no-till and chisel plowing (mulch-tillage) reduced runoff of atrazine, simazine and cyanazine by more than 90 percent, compared with moldboard plowing.[33] Ridge-till has reduced herbicide runoff by an average 42 percent in natural rainfall studies.[32]

Because no-till often increases water infiltration, some feared that this tillage system might also increase leaching of chemicals through the soil profile to groundwater. Several studies have shown, however, that no-till either had little impact on nitrate leaching or decreased leaching slightly.[34, 35, 36] A few studies have shown increased leaching of certain pesticides to shallow depths in no-till compared with tilled soil,[37, 38] while others have documented less leaching of pesticides with no-till.[39, 40, 41, 42, 43, 44] As crops genetically modified to tolerate the herbicide glyphosate are increasingly planted in no-till systems, leaching potential should be lessened, because this compound binds tightly to the soil and is highly unlikely to move to groundwater. Reductions in leaching of other herbicides used in no-till may be due to greater microbial activity degrading the pesticide, greater organic matter adsorbing the pesticide or to water bypassing upper layers of soil containing the pesticide, due to flow down macropores. The mucous lining of earthworm burrows has also been shown to adsorb pesticides.[45] When the herbicide atrazine was poured down night crawler burrows, concentrations exiting at the bottom were reduced tenfold. Although conservation tillage has not always reduced pesticide leaching, because of favorable results in many studies, no-till is recommended as a practice to reduce pesticide leaching by some water quality specialists.[42, 44]

Decreased flooding, increased soil moisture

Reduced runoff due to conservation tillage also is associated with decreased flooding. Such a decrease was documented on the Pecatonica River in Wisconsin. A decrease in flood peaks and winter/spring flood volumes accompanied by an increase in base flow (due to infiltration) was documented. The changes were not correlated to climatic variations, reservoir construction or major land use changes but appeared "to have resulted from the adoption of various soil conservation practices, particularly those involving the treatment of gullies and the adoption of conservation tillage."[46]

Conservation tillage not only reduces water loss through runoff, it also reduces evaporation losses so that more soil moisture is preserved for crop production. In one study, cumulative water losses for the first five hours after tillage were 0.113 in. (0.29 cm) with conventional tillage vs. 0.052 in. (0.13 cm) for no-till.[47] In Kentucky, annual evaporation was reduced by 5.9 inches (15.0 cm) with no-till.[48] In areas where rainfall is limited, such as the Great Plains of the United States, grain production is made possible by fallowing land. No crop is planted for a year or part of a year so that soil moisture can be stored for use by the next planted crop. Weeds must be controlled during the fallow period to prevent them from drawing moisture out of the soil. Traditionally, weeds in fallow land were controlled by repeated tillage operations. However, tillage increases evaporation losses, causes wind and water erosion and disturbs wildlife habitat. Chemical fallow or ecofallow systems, which use herbicides to control weeds, have been developed for crops planted no-till following the fallow period.[49, 50] In Kansas, Norwood[51] found that water use efficiency was increased by 28 percent in no-till corn grown in a wheat-corn-fallow rotation, compared with conventional tillage. Corn yields were 31 percent higher with no-till. Widespread adoption of these conservation systems across the Great Plains has improved the economic welfare of farmers, as well as reduced erosion and improved wildlife habitat.

Irrigation efficiency also is improved by conservation tillage. More moisture from rainfall is stored, and more of applied irrigation water infiltrates to be used by crops. The residue on the soil surface also reduces crop evapotranspiration. Improved irrigation efficiency benefits farmers by increasing yields and decreasing pumping and irrigation water costs while protecting aquifers from depletion.

Reducing "greenhouse gases" while enriching the soil

Soil organic matter is considered to be the largest terrestrial carbon pool[52] and influences the atmospheric content of CO_2, CH_4 and other greenhouse gases.[53] Soil organic matter can serve as a source or a sink for atmospheric carbon.[54] Conservation tillage, especially no-till, increases the ability of soil to store or sequester carbon, simultaneously enriching the soil and protecting the atmosphere.

Tillage increases the availability of oxygen, thus speeding the microbial decomposition of soil organic matter. Decomposition releases large quantities of CO_2, a "greenhouse" gas linked to global climate change. A 10-year analysis of common cropping systems in the United States showed that no-till farming had far less global warming potential than conventional tillage or organic systems.[55] The researchers calculated the types and amounts of greenhouse gases that were emitted or stored by each cropping activity and calculated a

numerical value called the gross warming potential (GWP) for each. Conventionally plowed fields had the highest net GWP (114), compared with 41 for organic farming and 14 for no-till (Figure 5).

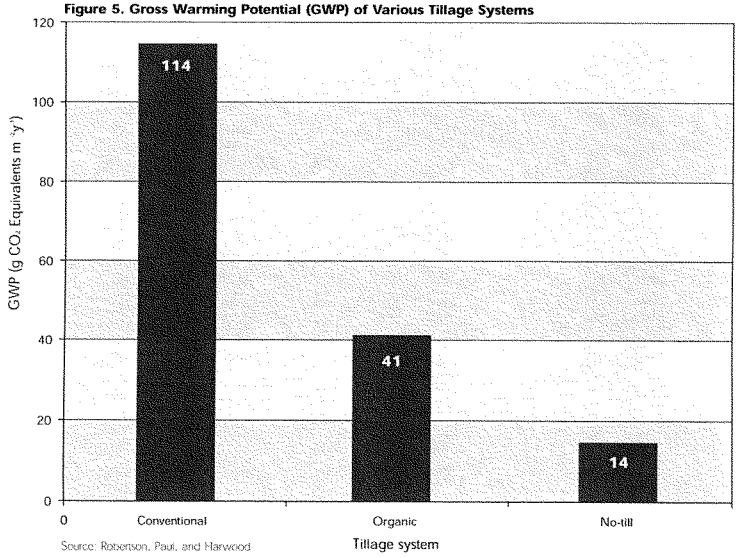
By converting land to no-till production, rather than depleting soil organic matter, organic matter can be increased, sequestering CO_2 from the atmosphere. Soil organic matter content has increased by 1,000 lb/acre/year (1120 kg/ha/year) in some no-till studies.[5,56] That is equivalent to 590 lb/acre (661 kg/ha) carbon stored per year, compared with the 15-20 lb/acre (17-22 kg/ha) carbon that was burned as fuel to produce the crop.

Kern and Johnson[57] projected changes in atmospheric carbon due to several scenarios involving adoption of conservation tillage in the United States until the year 2020. Converting from conventional tillage to no-till on 57 percent of crop acres would result in a gain in soil organic matter of 80 trillion to 129 trillion grams (Tg) (Tg = 1012g = 1 million metric tons = 1.102 million tons) and would remove a like amount of carbon from the atmosphere.

Lal *et al.*[55] have reviewed the importance of cropland as a source and sink for atmospheric carbon. The estimated 55,000 million metric tons (MMT) of historic soil-C loss from cultivated soils worldwide accounts for about 7 percent of the current atmospheric inventory. They conclude that cropland soils potentially can sequester a considerable part of this lost carbon with adoption of practices such as conservation tillage. Considering U.S. cropland, about 5,000 MMT of soil organic carbon has been lost from its pre-agricultural levels. The authors conclude: "One reasonably can assume that cropland potentially can sequester 4,000 to 6,000 MMT, with an average of 5,000 MMT in cropland soils – potentially more, with new technologies and proper management."

Reicosky *et al.*[58] measured CO_2 released from soil after tilling wheat stubble with various implements in the fall. Over a 19-day period, one pass of a moldboard plow caused five times as much CO_2 to be lost from the soil, compared with untilled plots. More organic matter was oxidized in 19 days than was produced all year in wheat straw and roots, helping explain why organic matter content has steadily declined in tilled

Figure 5. Gross Warming Potential (GWP) of Various Tillage Systems



Source: Robertson, Paul, and Harwood

soils until equilibrium is reached. Organic matter contents of agricultural soils in the United States have declined by as much as 50 percent or more due to this phenomenon. In effect, organic matter has been "mined" by agriculture. For example, the Morrow Plots at the University of Illinois were first established in 1876 and have been maintained in constant cropping systems to date.[59] Soil organic matter was first measured in 1903, when levels were about 40 tons per acre (44,800 kg/ha). By 1973, under continuous corn production, organic matter content had dropped to about 20 tons per acre (22,400 kg/ha). Conservation tillage systems, especially no-till systems, do not simply stop organic matter loss; they can cause soil organic matter content to increase. Reicosky *et al.* and Reeves found that organic matter has increased by as much as 1,800 pounds/acre/year (2000 kg/ha/year) in long-term no-till studies.[58, 60]

Improved air quality

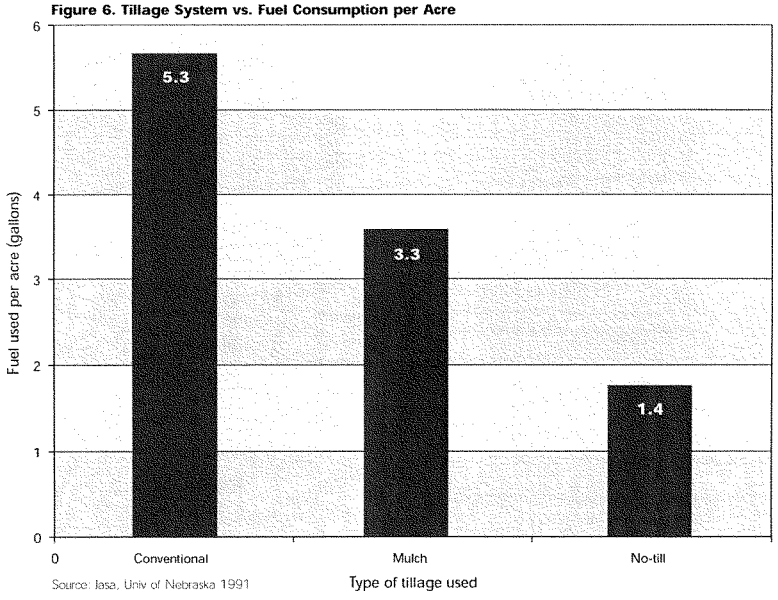
Conservation tillage, by reducing wind erosion, also reduces the amount of dust that can enter the atmosphere. In some regions, dust from agricultural fields is a major air quality concern. Wind-eroded dust also carries other contaminants such as pesticides and nutrients into the atmosphere where they are later deposited by rainfall into aquatic systems.[61, 62]

Conservation tillage is also an alternative to the practice of burning residue left on fields. In some regions of the United States, crop residue is burned to facilitate planting of rotational crops. This practice not only causes air pollution with smoke but also releases CO_2 into the atmosphere and reduces soil quality by destroying organic matter. Adoption of conservation tillage systems has significantly reduced the practice of burning crop residues.

No-till saves 3.9 gallons of fuel per acre

As tillage operations in crop fields are reduced or eliminated with the adoption of conservation tillage, fuel consumption declines. Fuel usage for no-till may decrease from 3.5 gal/acre (32.7 L per ha) to 5.7 gal/acre (53.3 L per ha) depending on the number of tillage trips reduced, clay and moisture content of the soil, and type of tillage operations eliminated.[57] Moldboard plowing typically uses 5.3 gal/acre, chisel

Figure 6. Tillage System vs. Fuel Consumption per Acre



Source: Iasa, Univ of Nebraska 1991

plowing 3.3 gal/acre, and no-till 1.4 gal/acre.[63] For every gallon of diesel fuel saved, 3.72 lbs of CO_2 are not released.

In 2002, 15 million acres (6.1 million hectares) of corn and 26 million acres (10.5 million hectares) of soybeans were grown in no-till systems in the United States, amounting to 41 million no-till acres (16.6 million hectares). Using the 3.9 gallons per acre estimated savings from no-till,[62] a net savings of 160 million gallons (605 million liters) of fuel per year is being realized in the no-till production of just these two crops. The 55.3 million no-till acres (22.4 million hectares) planted from all crops in the U.S. in 2002 would account for a savings of 216 million gallons (817 liters) of fuel that year. Mulch-tillage saves two gallons per acre of fuel compared with conventional tillage, accounting for a fuel savings of 90 million gallons on the 45 million acres (18.2 million hectares) of mulch-till systems. The combined fuel reduction from no-till and mulch-till systems therefore accounted for a savings of 306 million gallons of fuel.

Significant reductions in tillage have occurred as herbicide-tolerant crop varieties have facilitated conversions to conservation tillage. A 2001 American Soybean Association survey[64] asked soybean growers if and how much tillage had been reduced between 1996 and 2001 (the period of time glyphosate-tolerant soybeans had been available). Soybean growers responded that they had reduced tillage by an average 1.8 passes per growing season. One tillage pass consumes about 0.7 gallons of diesel fuel per acre.[65] Thus, soybean growers have reduced fuel consumption by 1.26 gallons per acre since the introduction of glyphosate-tolerant soybeans. With more than 56 million acres of biotech soybeans planted in 2001, a savings of 70 million gallons of fuel occurred just from this crop. In 2002, 75 percent of all soybeans planted were biotech soybeans. (USDA/NASS)

TRENDS LINK BIOTECH, CONSERVATION TILLAGE

Many factors determine whether a farmer will practice conservation tillage. Cultural factors, climate, soil type, equipment availability, moisture content, tradition and other considerations all can be at play in making tillage decisions. Weed control is among the most important factors, at least in commonly grown row crops. The development of herbicide-tolerant crops has given farmers a new, versatile technology for controlling weeds. It has removed much of the uncertainty in weed control that prevented farmers from abandoning tillage.

Since the development of herbicide-tolerant soybeans and cotton, there have been marked increases in conversion to no-till, the system most dependent on herbicide performance. In other crops, where the herbicide-tolerant technology is not available, there have not been large increases in conservation tillage.

Farmers who use herbicide-tolerant seeds are more likely to engage in conservation tillage practices than in conventional tillage practices. Furthermore, farmers who use herbicide-tolerant seeds practice conservation tillage to a greater degree than farmers who do not use the new technology.

These facts and trends indicate that the advent of herbicide-tolerant crops, developed through biotechnology, has solidified the acreage converted to conservation tillage during the early 1990s and has contributed to the steady growth of no-till acreage since 1996, when the crops were introduced. Biotechnology may well have the potential to facilitate even more no-till.

An analysis of governmental, independent and industry data, as well as grower surveys, shows a strong association between herbicide-tolerant crops and growers' decisions to increase their level of crop residue. The following four findings emerge:

1. Improvements in weed control, including the adoption of biotech herbicide-tolerant crops, are important reasons for initial adoption and continuance of no-till.

Because the primary reason for tillage is weed control, many farmers, assured of weed control without disturbing the seedbed, will choose to reduce tillage. Herbicide-tolerant crops provide farmers with an important advancement in weed control capability.

Past surveys of farmers, assessing reasons for not adopting conservation tillage, consistently found that weed control was one of the greatest deterrents.[66] In 1991, Iowa farmers were surveyed on their attitudes about tillage. Weed control was most important to farmers considering tillage changes. Farmers who had tried no-till were asked to identify advantages or disadvantages to the system. Sixty-eight percent responded that weed control was a disadvantage. Only chemical costs (70 percent responding) ranked higher as a disadvantage.[67]

If farmers had greater confidence in no-till weed control systems, more farmers could be expected to convert to no-till. Conclusions from these surveys indicate that improvements in weed control, including the adoption of biotech herbicide-tolerant crops, are important reasons for initial adoption and continuance in no-till systems.

In 1999, corn and soybean producers in Iowa were surveyed to determine their tillage practices, yields and attitudes about tillage.[63] Among no-till farmers, 68 percent felt that herbicide effectiveness had increased in the last five years; 56 percent of farmers who had tried but quit no-till felt effectiveness had increased; and 34 percent of farmers who had never tried no-till felt herbicides were more effective. Thus, it is apparent that no-till adopters have more confidence in their weed control systems. Consistent weed control offered by herbicide-tolerant crop systems could increase the confidence of all farmers, resulting in the increased adoption of no-till by farmers who have never tried it and reducing the number of first time no-tillers who revert back to conventional tillage.

An American Soybean Association random survey of soybean growers planting 200 acres or more in the 19 major soybean-producing states documents the importance of glyphosate-tolerant soybeans in facilitating conversion from conventional tillage to no-till and reduced tillage. Soybean growers reported having reduced tillage by an average 1.8 passes from 1996 to 2001, during the period of time that glyphosate-tolerant soybeans were available. Average crop residue cover increased from 28 percent to 49 percent. During the same period, no-till soybean acres in the American Soybean Association survey more than doubled to 49 percent, and reduced tillage acres increased by more than one-fourth, to account for 83 percent of soybean acres. During this time, 53 percent of growers reported making fewer tillage passes, 73 percent left more crop residue on the soil surface, and 48 percent had increased their no-till acres.[64]

To what can these increases be attributed? Sixty-three percent of soybean growers who increased their crop residue between 1996 and 2001 cited glyphosate-tolerant technology as the key factor that made it possible for them to reduce tillage or increase residue.[64] That was an unaided response to the question: "In the past five years, what changes in technology such as equipment, chemicals or seed have made it possible for you to reduce tillage or increase crop residue in soybeans?"

When asked which of six factors had the greatest impact toward the adoption of reduced tillage or no-till during the past five years, growers indicated:

- The introduction of glyphosate-tolerant soybeans 54 percent.
- Availability of over-the-top or in-crop herbicides 12 percent.
- The cost of burndown herbicides 6 percent.
- The availability of burndown herbicides 3 percent.

A total of 75 percent of surveyed farmers felt some aspect of weed control was the greatest factor in adopting reduced tillage or no-till. Availability of and improvements in no-till drills garnered responses of 9 and 15 percent respectively.[64]

In a Canadian survey, 26 percent of canola growers said they had increased their conservation tillage practices because of herbicide-tolerant technology.[69] Their average increase was 69 percent, which translates into 2.6 million acres or 1.05 million hectares in western Canada having been positively impacted by increased conservation tillage practices since the introduction of the technology.

Weed control is similarly important to cotton producers. A USDA survey showed that 76.3 percent of herbicide-tolerant cotton growers said they planted herbicide-tolerant varieties because of increased yields through better weed control, and 18.9 percent cited decreased herbicide input costs.[70]

Competition brought on by herbicide-tolerant technology has resulted in an overall lowering of weed control costs, thus addressing another concern about moving to no-till. Gianessi and Carpenter calculated that U.S. soybean growers spent $220 million less on weed control in 1998 compared with 1995, after the added costs of glyphosate-tolerant seed were factored in.[71] These benefits are supported by the rapid adoption of the technology since its introduction in 1996. Glyphosate-tolerant soybeans were planted on 75 percent of soybean acres in 2002, and glyphosate-tolerant cotton was planted on 58 percent of cotton acres.[72] In Canada, herbicide-tolerant varieties were planted on an estimated 55 percent of the 12 million acres (4.9 million hectares) of canola produced in 2000.[68]

Biotech crops have given farmers a new weed management tool, allowing the post-emergence use of highly effective broad-spectrum herbicides. Perennial weeds are often prevalent in conservation tillage, especially in no-till systems. Many perennials have been noted to

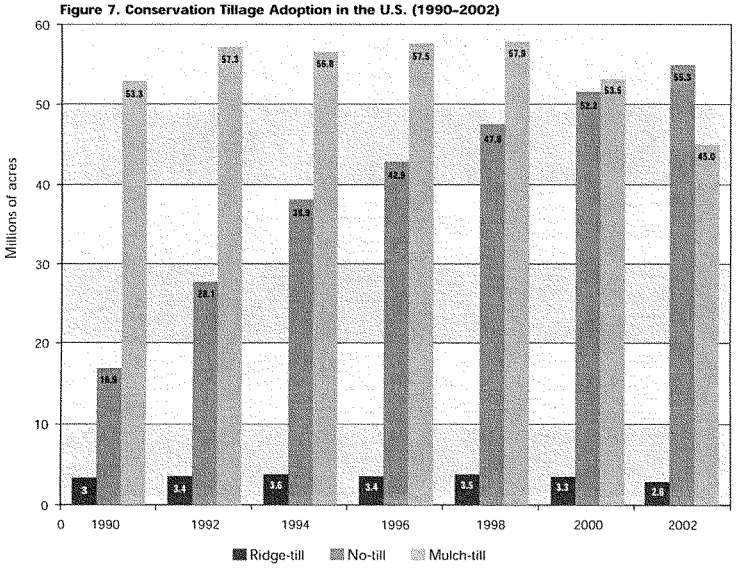
increase with conservation tillage.[7] The ability to apply glyphosate over tolerant crops, made possible by biotechnology, now allows control of tough perennials that escape most other herbicides. The risk of suffering poor weed control has been reduced significantly. Biotech crops are not required for the practice of conservation tillage or no-till, but the herbicide-tolerant crops developed through biotechnology have provided farmers with an additional weed management tool, solving some weed control problems faced by conservation tillage farmers.

2. No-till, the system that most depends on herbicide performance, has grown steadily since 1994. Nearly all of this growth occurred in crops where herbicide-tolerant technology is available.

CTIC tillage surveys are based on criteria it developed to define conservation tillage (at least 30 percent residue cover after planting). Mulch-till, ridge-till and no-till are the various forms of conservation tillage. Figure 7 shows national adoption trends for these systems from 1990 through 2002. Since 1996, conservation tillage adoption in the United States has remained fairly constant – about 36 percent of all annually planted cropland or between 103 million and 109 million acres. Thus, total conservation tillage acres appear to have temporarily reached a plateau. However, adoption of no-till, the most soil-conserving form of conservation tillage, continues to increase, rising from 40.9 million acres (14.7 percent of all cropland) in 1995 to 55.3 million acres (19.6 percent of all cropland) in 2002. This represents a growth of 35 percent in no-till since biotech crops were introduced in 1996, according to CTIC's National Crop Residue Management Survey.

The fact that no-till acreage increased while overall conservation tillage has remained steady indicates that growers who earlier made a commitment to some form of reduced tillage decided to leave even more residue on their fields. The 2001 American Soybean Association survey found that 73 percent of soybean growers were leaving more crop residue than five years earlier, and 48 percent of them had increased their no-till acreage from 1996 levels. As stated earlier, 75 percent of soybeans planted in 2002 were glyphosate-tolerant varieties.

Figure 7. Conservation Tillage Adoption in the U.S. (1990–2002)

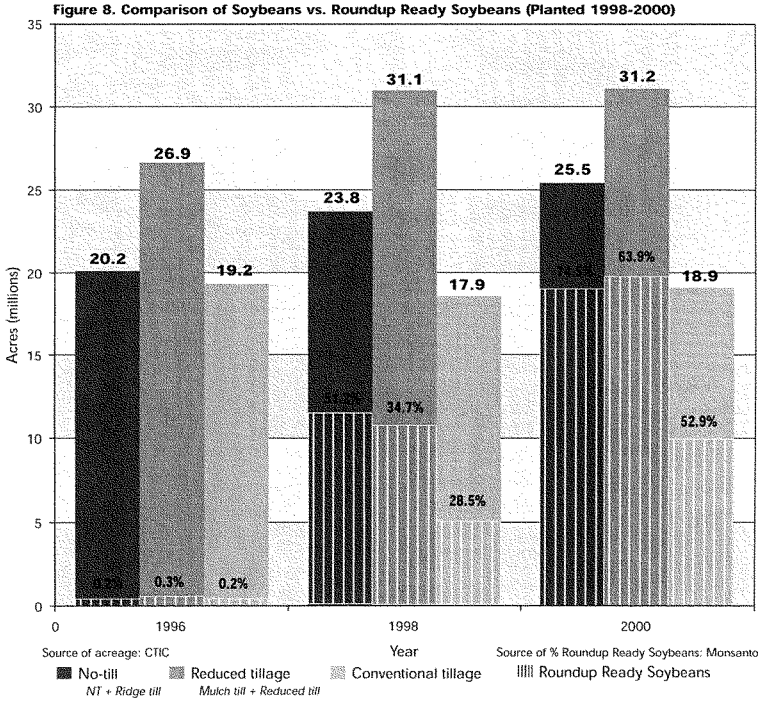


Soybeans and cotton have the highest percentage of biotech crops and account for half of the total no-till acres planted in the U.S. in 2002, according to CTIC figures. It is also significant that the two crops for which glyphosate-tolerant (Roundup Ready®) varieties have been rapidly adopted continue to show increases in adoption of no-till. No-till soybean acres increased from 19.3 million acres (7.8 million hectares) in 1995 (before glyphosate-tolerant crops) to 26 million acres (10.5 million hectares) in 2002. No-till cotton acres increased from 0.5 million (0.2 million hectares) in 1996 (before glyphosate-tolerant crops) to 2 million acres (0.82 million hectares) in 2002. Glyphosate-tolerant soybean varieties have been available since 1996, and cotton varieties since 1997. Glyphosate-tolerant corn was first marketed in 1998. Herbicide-tolerant canola became available in Canada in 1996 and the United States in 1999. Only about 1.5 million acres of canola were planted in the United States in 2000.

3. There is a clear association between sustainable tillage practices and biotech crops.

Table 2 shows national percentages of tillage categories planted to glyphosate-tolerant soybeans, cotton and corn for 1998-2000. While farmers using all tillage systems have adopted the glyphosate-tolerant crops, conservation tillage farmers are much more likely to use the biotechnology crops. For example, in 1998, no-till soybeans were nearly twice as likely to be planted to glyphosate-tolerant varieties compared with conventional varieties, while no-till cotton was more than twice as likely to be planted to glyphosate-tolerant varieties. Adoption of glyphosate-tolerant crops by conservation tillage farmers continues to grow. In 2000, 52.9 percent of conventional tillage, 63.9 percent of reduced tillage, and 74.5 percent of no-till soybean acres were planted to glyphosate-tolerant varieties. Cotton acres planted to glyphosate-tolerant varieties for

Figure 8. Comparison of Soybeans vs. Roundup Ready Soybeans (Planted 1998-2000)



2000 were 46.8 percent of conventional tillage, 63.2 percent of reduced tillage and 86.2 percent of no-till. In 2000, 4.3 percent of conventional tillage, 4 percent of reduced tillage and 7 percent of no-till corn was planted to glyphosate-tolerant varieties.

No-till cotton is constrained by the predominance of furrow irrigation and boll-weevil eradication programs in some regions, such as California and Arizona, which restricts conversion to no-till. In other cotton-growing regions, producers who tried the relatively new no-till system for cotton used herbicide-tolerant varieties to facilitate the change. In Arkansas in 1998, only 6.7 percent of conventionally tilled cotton was planted to glyphosate-tolerant varieties, while 97.8 percent of no-till cotton acres were planted to the biotech varieties.[74]

In 2000, glyphosate-tolerant cotton was planted on 97, 96, 95 and 94 percent of no-till cotton in Georgia, Tennessee, Alabama and North Carolina, respectively.[75] The high adoption rate of glyphosate-tolerant cotton by no-till producers illustrates the utility of this technology in conservation tillage. In 2000, glyphosate-tolerant corn was planted on only 5 percent of corn acres in the United States, due in large part to a concern about export restrictions. About 7 percent of all no-till corn acres planted in 2000 were glyphosate-tolerant.

The American Soybean Association survey of grower practices confirms the greater usage of glyphosate-tolerant soybeans in no-till and reduced tillage systems. In the 19-state area represented by the survey, glyphosate-tolerant soybeans were planted on 36.8 million conservation tillage acres and only on 5.3 million conventionally tilled acres.[63] Clearly, with the glyphosate-tolerant seeds going disproportionately to the soybean acres in conservation tillage, farmers understand the value of the technology to reduced tillage systems.

4. Farmers who don't use herbicide-tolerant seeds are not as likely to engage in conservation tillage.

While it is clear that many farmers who use traditional weed control systems also participate in conservation tillage, there is significantly greater participation among those soybean and cotton farmers who use herbicide-tolerant varieties developed through biotechnology. Table 3 shows results of the American Soybean Association survey[63] comparing practices of glyphosate-tolerant soybean adopters to non-adopters. Glyphosate-tolerant soybean growers planted more no-till and reduced till acres than non-adopters. For the period 1996 to 2001, 52 percent of glyphosate-tolerant soybean adopters had increased no-till acres, compared with 21 percent of non-adopters. Fifty-eight percent of adopters reported reducing tillage passes, with 20 percent of non-adopters reducing tillage passes.

Likewise, in Canada, 50 percent of canola growers who used herbicide-tolerant varieties participated in conservation tillage practices, while only 35 percent of non-adopters practiced conservation tillage.[68]

Table 2: Adoption of glyphosate-tolerant (Roundup Ready) crop technology by tillage system for U.S. soybeans, corn and cotton 1998-2000

	Percent of Acres Planted to Glyphosate-Tolerant Crop		
Year	Conventional Tillage	Reduced Tillage	No-till
Soybeans			
1998	28.5	34.7	51.2
1999	47.0	55.9	70.7
2000	52.9	63.9	74.5
Cotton			
1998	21.3	37.7	57.2
1999	35.0	51.4	65.8
2000	46.8	63.2	86.2
Corn			
1998	1.2	1.1	1.8
1999	3.2	2.9	4.4
2000	4.3	4.0	7.0

Source: Monsanto Company

Table 3: American Soybean Association 2001 survey of U.S. soybean grower practices of glyphosate-tolerant soybean adopters and non-adopters, 1996 to 2001

Characteristics	Glyphosate-tolerant soybean growers	Non-glyphosate-tolerant soybean growers
Percent of 2001 soybean acres in no-till or reduced till	84	72
Percent of growers having more no-till soybeans vs. five years ago	52	21
Percent of growers making fewer tillage passes vs. five years ago	58	20
Percent of growers leaving more crop residue vs. five years ago	76	57
Sample size-unweighted base	393	59

Source: American Soybean Association 2001

SUMMARY STATEMENT

Herbicide-tolerant crops developed through biotechnology have provided farmers with an additional weed management tool. They have solved some weed control problems faced by conservation tillage farmers and simplified weed control. An analysis of surveys conducted since the introduction of herbicide-tolerant crops strongly supports the conclusion that these crops developed through plant biotechnology are facilitating the continued expansion of conservation tillage, especially no-till. As more acres are converted to conservation tillage, and especially no-till, significant environmental benefits will be derived.

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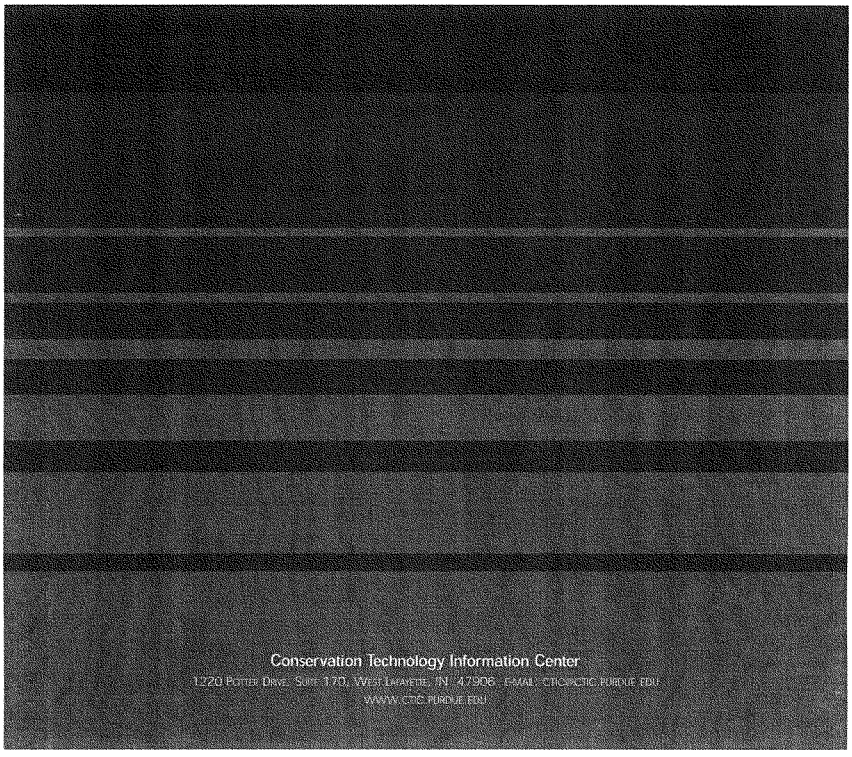
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Off-Farm Income, Technology Adoption, and Farm Economic Performance

Jorge Fernandez-Cornejo, with contributions from Ashok Mishra,
Richard Nehring, Chad Hendricks, Malaya Southern
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Off-Farm Income, Technology Adoption, and Farm Economic Performance

Jorge Fernandez-Cornejo, with contributions from Ashok Mishra, Richard Nehring, Chad Hendricks, Malaya Southern, and Alexandra Gregory

Abstract

The economic well-being of most U.S. farm households depends on income from both onfarm and off-farm activities. Consequently, for many farm households, economic decisions (including technology adoption and other production decisions) are likely to be shaped by the allocation of managerial time among such activities. While time allocation decisions are usually not measured directly, we observe the outcomes of such decisions, such as onfarm and off-farm income. This report finds that a farm operator's off-farm employment and off-farm income vary inversely with the size of the farm. Operators of smaller farm operations improve their economic performance by compensating for the scale disadvantages of their farm business with more off-farm involvement. Off-farm work reduces farm-level technical efficiency, but increases household-level technical efficiency. And adoption of agricultural innovations that save managerial time is associated with higher off-farm income.

Keywords: Off-farm income, farm households, economic performance, managerial time, scale economies, scope economies, technical efficiency, technology adoption, farm size.

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Summary

U.S. farmers must make a host of decisions relating to their farms' operation, including what to grow, when to grow it, in what quantities, and by what methods. Often overlooked in this calculation, but factoring heavily in the diversity of U.S. farms and farm households, is the fact that most operators split their time between farm and nonfarm activities. Large farms are typically able to economize on inputs and better coordinate stages of production. Smaller farms, though often unprofitable from a farm business perspective, have endured by being part of household enterprises that combine farm and off-farm activities. Their operators' onfarm decisions, from choice of technology to choice of specialty, are often influenced by off-farm commitments and income.

What Is the Issue?

Onfarm and off-farm activities compete for limited managerial time (mainly of the operator and spouse). How farm operator households allocate their time largely affects production decisions (such as technology adoption), economic performance, and the household's economic well-being.

The extent of off-farm work and its relationship with farm economic performance may have important policy implications. For example, government policies for agriculture (via conservation, research and development, extension, and commodity programs) may affect farm households differently, depending on the relative importance of onfarm versus off-farm income. And the effectiveness of policies promoting adoption of farm technologies might be improved by taking into account the different demands on managerial time and the relative ability of the farm household to accommodate those demands.

What Did the Study Find?

Operators of smaller farms typically participate more in off-farm employment, work more hours off the farm, and have higher off-farm income than operators of larger farms. In 2004, farm households with farm sales less than $10,000 had average off-farm earned income of $54,600, while households with farm sales of $500,000 – $1 million averaged only $30,100. More than 58 percent of operators with farm sales less than $10,000 reported off-farm hours worked in 2004, versus less than 20 percent for operators of farms with sales of $500,000-$1 million.

As previous studies have shown, **off-farm work is less likely on farms with labor-intensive enterprises** such as dairy. Moreover, dairy farmers who do work off the farm tend to require higher compensation to do so than farmers producing other commodities. Off-farm work has also been shown to be positively related to urban proximity and to the education and experience of the operator and spouse.

Including off-farm income-generating activities improves the overall economic performance of the farm household. Off-farm income clearly adds to total household income, but it can also improve efficiency and other

measures of performance of the farm household. Our estimates for corn and soybean farms show that households engaged in off-farm income-generating activities together with the production of traditional farm outputs have cost savings of 24 percent relative to carrying out those activities separately. The savings likely arise from the sharing of managerial expertise (and its many components, such as accounting and information processing skills, sales expertise, administrative and technical know-how, etc.) between onfarm and off-farm activities. For example, management skills acquired in farming might be applicable to (and shared with) a nonfarm business, and vice-versa.

From a farm business perspective, operators of smaller farms have a greater **incentive to expand**. However, from a household perspective (including off-farm income-generating activities), operators of small farms have a reduced tendency to increase their farm size.

Large farms are generally more efficient than smaller farms in transforming farm inputs into outputs, given the technology at their disposal. But focusing on farm inputs and outputs alone is misleading because off-farm income-generating activities are increasingly important in determining economic performance of the farm household.

When off-farm activities are included, farm household-level efficiencies are higher than farm-level efficiencies across all farm sizes, and efficiency gains from integrating off-farm work into the output portfolio are relatively greatest for smaller farms. As a result, household-level efficiencies of smaller farms are comparable to farm-level efficiencies of larger farms. This suggests that households operating small farms have partially adapted to shortfalls in farm-level performance by increasing their off-farm income.

In addition to its links with the farm business, as traditionally examined, farmers' technology choices are closely related to off-farm income. Higher off-farm income is significantly related to the adoption of technologies that economize on management time (management saving such as herbicide-tolerant crops, conservation tillage). For example, a 16-percent increase in off-farm household income is associated with a 10-percent increase in the probability of adopting herbicide-tolerant (HT) soybeans. Household income from onfarm sources is not significantly associated with adoption of these technologies, but total household income (including income from off-farm sources) is. On the other hand, lower off-farm income is significantly related to adoption of managerially intensive technologies (such as precision farming). For example, an 8-percent decrease in off-farm income is associated with a 10-percent increase in the probability of adopting yield monitors, a key component of precision agriculture. These findings corroborate a tradeoff between household/operator time spent in onfarm and off-farm activities. Households operating small farms devote more time to off-farm opportunities and are more likely to adopt management-saving technologies.

How Was the Study Conducted?

To examine the relationships between off-farm income, farm and household characteristics, and economic performance of U.S. farm households, we developed econometric models and estimated them using USDA's Agricultural Resource Management Survey (ARMS) data for several years (1996-2001). To examine the relationship between off-farm work and economic performance of farm households (including economies of scale and scope, and economic efficiency), we compared estimates obtained using traditional farm-level models to estimates obtained using household-level models (including off-farm income-generating activities along with traditional farm outputs such as crops and livestock). To examine the relationship between off-farm income and technology adoption, we developed a model that incorporates the adoption decision into the agricultural household framework. We examined the interaction of off-farm work and adoption of agricultural technologies of varying managerial intensity, including herbicide-tolerant crops, precision agriculture, conservation tillage, and Bt (*Bacillus thuringiensis)* corn, after controlling for other factors.

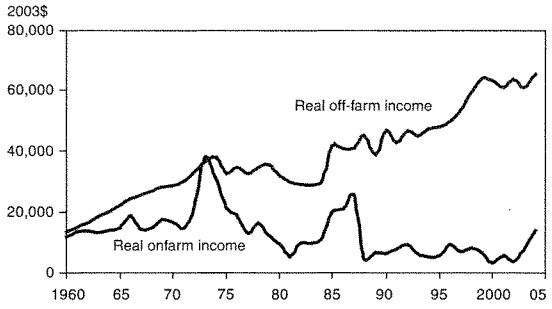
Introduction and Overview

Decisionmakers (mainly farm operators and their spouses) are a major determinant of farms' economic performance. The effort and ability to manage land, water, machinery, and other inputs— as well as adoption of technologies and production practices—can help secure farm business success and the economic well-being of a farm household. However, many farm operators (and other household members) use a large share of their time in off-farm income-generating activities. Consequently, for many farm households, economic decisions (including technology adoption and other production decisions) are likely to shape and be shaped by the allocation of managerial time to such activities. While time allocation decisions are usually not measured directly, we observe the outcomes of such decisions, such as onfarm and off-farm income.

Off-farm income (largely earned income from employment and off-farm business income) received by U.S. farm operators and their spouses has risen steadily over recent decades and now constitutes the largest component of farm household income (fig. 1a, b). The impact of off-farm income is felt particularly by households operating small farms, allowing many of them to survive and even flourish to an extent not thought possible 20 or 30 years ago (Gardner, 2005). In addition, the growth in off-farm income over the last 40 years reduced income inequality among farm households and helped U.S. farmers' average incomes overtake those of the nonfarm population (Gardner, 2002).

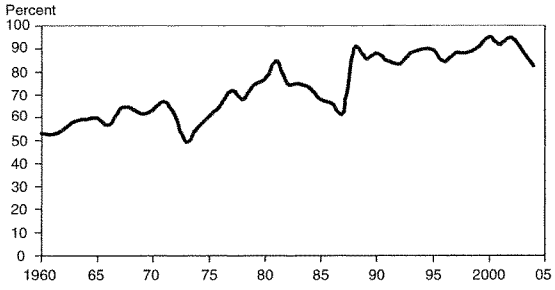
This report examines the empirical relationships between off-farm income, farm household characteristics, production decisions (particularly technology adoption), and various measures of economic performance for U.S. farm households. This research provides insights into farmers' choices in the context of farm/household integration and helps improve our under-

Figure1a
Farm household income, U.S. average 1960-2004



Sources: USDA, ERS. Deflator used to calculate real income is the consumer price index (CPI-U) from the Bureau of Labor Statistics.

Figure 1b
Off-farm income share of total farm household income, U.S. average, 1960-2004



Sources: 1960-2003: USDA farm household income estimates over time, ERS farm structure briefing room, http://www.ers.usda.gov/Briefing/FarmStructure/Data/historic.htm; 2004: Covey et al., 2005.

standing of the pace of technological innovation and its relation to the structure of agriculture.

The report also suggests the need to analyze the economics of the farm business and farm household in an integrated framework and describes two approaches for doing so. We summarize statistics of off-farm work and income in U.S. farm households and examine the relationship between off-farm income and farm size, location, and household characteristics.

Our main research focus is to examine how off-farm work influences the economic performance of the integrated farm business and household. To do this, we expand traditional concepts of economic performance, such as economies of scale and efficiency, to incorporate onfarm and off-farm income-generating activities of household members. In addition, we examine the relationship between off-farm income and the adoption of agricultural technologies of varying managerial intensity, namely herbicide-tolerant crops, precision agriculture, conservation tillage, and Bt (*Bacillus thuringiensis*) corn.

An Integrated Approach

While increasing household income, off-farm activities also compete for managerial time (mainly of farm operators and their spouses), which may affect the economic performance of the farm business. Consequently, economic decisions (including technology adoption and other production decisions) are likely to shape and be shaped by the underlying allocation of time within the farm operator household. So, rather than examining the farm business or farm household in isolation, an integrated approach captures the interplay of farm and nonfarm considerations and contributions.

Despite its importance, the role of off-farm income has been largely neglected in empirical analyses of farm economic performance and technology adoption.[1] Some exceptions include Gardner (2001), Boisvert (2002), Goodwin and Mishra (2004), Fernandez-Cornejo et al. (2005), Nehring et al. (2005), Paul and Nehring (2005), and Chavas et al. (2005).[2] One reason for this lack of studies may be the modeling and data challenges in moving from the traditional unit of analysis (the farm business) to the farm household.

While agricultural economists have made major contributions in understanding farm production functions, they may not have exploited as fully the concept of the household production function (Offutt, 2002). In this context, the allocation of time (and money) of household members to production, consumption, and other activities is particularly important. An integrated firm-household perspective was suggested back in 1952 by E.O. Heady, who observed that "the firm-household complex is important not only to defining the organization of resources and family activities which will maximize utility at a given point in time but also in helping to explain uncertainty precautions, capital accumulation, soil conservation, and other production-consumption decisions, which relate to time."[3]

Approaches To Integrate Off-Farm Work and Farm Production

Two approaches are used in this report to model the interaction of off-farm income-generating activities with traditional farm production activities. The unifying notion underlying the two approaches is that managerial time is a key resource in both onfarm and off-farm activities.

In one approach, we expand the agricultural household model to include the technology adoption decision together with the off-farm work decisions by the operator and spouse. The agricultural household model describes how a farm household allocates its time (and other resources) among producing commodities, earning off-farm income, leisure, and home production.[4] The model assumes that the farm household maximizes its utility subject to constraints on its time (including work and leisure), income, and production technology (production function). Household members derive utility from goods purchased for consumption, leisure, and factors exogenous to current household decisions, such as human capital, household characteristics, and weather. Using this model, we examine the interaction of off-farm work and the adoption of agricultural innovations (both management saving like herbicide-tolerant crops, and management using like precision agriculture or integrated pest management—IPM), then obtain empirical estimates of the relationship between adoption of these technologies and farm household income.

Though the agricultural household model has intuitive appeal in modeling farm household behavior, it requires much in the way of assumptions and data (Offutt, 2002). Parameter estimation for the models spawned by the household production function often requires hard-to-get data, including consumption expenditures, farm and off-farm labor supply, farm and nonfarm outputs and inputs, assets, and prices for all goods, inputs, and labor. Also needed is information on technologies and participation in

[1]Economic researchers have been examining farm economic performance focusing on the farm business for several decades (Heady; Griliches; Dawson and Hubbard; Hallam). Another line of research has focused on the farm household and the labor allocation decisions by the operator and their spouses (Huffman, 1980, 1991; Lass, Findeis, and Hallberg, 1989; Lass and Gempesaw, 1992; Kimhi, 1994, 2004).

[2]Boisvert (2002) stressed not only the growing links between farming activities and off-farm labor markets but also the links between farm household activities, conservation payments, and agricultural pollution.

[3]Loosely, utility is a measure of satisfaction. Economists assume that people act if doing so gives them utility.

[4]The household model initially received a great deal of attention in studies of developing countries' agriculture because of the relative importance of consumption activities in such households. Agricultural economists have also applied these models in developed countries to examine how household members make decisions about the allocation of labor both on and off the farm (Huffman, 1980, 1991; Sumner, 1982; Lopez, 1985; Singh et al., 1986; Lass et al., 1989; Lass and Gempesaw, 1992; Kimhi, 1994, 2004; Mishra and Goodwin, 1997; Goodwin and Holt, 2002). Other analysts have examined income and wealth distributions and links between income instability and consumption/investment (El-Osta and Morehart; Mishra and Morehart). Lopez is one of the few to have considered labor supply and farm production decisions simultaneously. In a very recent application, Chavas et al. used a farm household model to investigate the economic efficiency of farm households in Gambia (Chavas et al., 2005).

government programs, as well as demographic data. For these reasons, it is sometimes necessary to use alternative methods. In this approach, we expand the concept of scope economies to include as output all income-generating activities, on or off the farm, in addition to the traditional farm outputs such as corn, soybeans, and livestock (Nehring et al., 2005). In addition, we estimate scale economies and technical efficiency, and compare results at the farm and household levels.

Scale and Efficiency

Scale Economies

A farm is said to have economies of scale (or increasing returns to scale) if the average cost declines as output (scale of production) increases. If a farm is subject to economies of scale, it is cost effective for that farm to increase all outputs simultaneously while holding the mix of outputs constant (costs would rise less than proportionally). Thus, the existence of scale economies suggests that farms can achieve lower average costs by becoming larger. Economists have established (under reasonable conditions) the equivalence between the information provided by the costs and the production technology (Carlton and Perloff, 2000). Based on the production technology, economies of scale may be viewed from an output or input perspective.

From an output perspective, the term elasticity of scale is used to measure the percent increase in output generated by a 1-percent increase in all inputs (Varian, 1992). There are increasing returns to scale if the elasticity is greater than 1; that is, an increase in overall inputs generates a more than proportionate increase in output. For example, a scale elasticity of 1.15 means that a 1-percent increase in inputs leads to a 1.15-percent increase in output. Conversely, if the elasticity is lower than one there are decreasing returns to scale; that is, an increase in overall inputs generates a less than proportionate increase in output. For example, a scale elasticity of 0.8 means that a 1-percent increase in inputs leads to a 0.8-percent increase in output. Constant returns to scale means that a 1-percent increase in overall inputs generates a 1-percent increase in output; in this case the elasticity of scale is equal to 1.

From an input perspective, a similarly defined scale elasticity measures the percent increase in inputs required to support a 1-percent increase in all outputs. In this case, returns to scale are increasing when the input-oriented scale elasticity is less than one. For example, if the scale elasticity of a farm is 0.75, it means that a 0.75-percent increase in inputs will be needed to support an output increase of 1 percent. This suggests that there is an incentive for the farm to grow larger. If the elasticity is equal to one (constant returns to scale), there are no scale economies available. In this report, we use an input perspective (input distance function, appendix 1).

Technical Efficiency

Economic efficiency can be decomposed into technical efficiency and allocative efficiency. A farm is technically efficient if it uses the minimum possible levels of inputs to produce a given level of output, given the technology. An allocative efficient farm produces a given output using the best (minimum cost) input proportions given prevailing input prices. Unless specified otherwise, the efficiency results discussed in this report involve technical efficiency.

Technical efficiency is the ratio of current to maximum possible or "best practice" production and it is calculated in this study using an input distance function (see appendix 1). Technical efficiency is defined relative to an "efficient frontier" and all farms operating on the efficient frontier are classified as 100 percent efficient with an efficiency score equal to 1. Farms using more inputs to produce a given output level than those on the efficient frontier are inefficient and their efficiency score is less than 1. Technical efficiency is often associated with managerial ability and experience.

Off-Farm Work and Income in U.S. Farm Households

Off-farm income received by farm operators and their spouses has risen steadily over recent decades (fig. 1a) as job opportunities have grown and technological progress, such as mechanization, has lessened onfarm labor needs. The off-farm income share of total household income of U.S. farmers rose from about 50 percent in 1960 to more than 80 percent over the past 10 years (fig. 1b). Most of the off-farm income was earned. On average, a farm household earned about $48,800 from off-farm sources in 2004, received about $18,500 in unearned income (Social Security, interest, etc), and netted nearly $14,200 from farming activities (Covey et al., 2005).[5] Fifty-two percent of farm operators worked off farm in 2004 (up from 44 percent in 1979). The share of spouses working off farm grew from 28 percent of spouses in 1979 to 45 percent in 2004 (Mishra et al., 2002; 2004 ARMS data).

The trend is similar in terms of hours worked (table 1). Average hours worked off farm by farm operators has increased (from 830 hours per year in 1996 to 1,022 in 2004), while the hours devoted to farm work did not change markedly (1,525 hours in 1996 and 1,574 in 2004). Similarly, the number of hours worked off the farm by spouses increased from 690 in 1996 to 809 in 2004.

Farmers' Motivations To Work Off Farm

Once seen as a "temporary response to the Great Depression," off-farm employment is now regarded as a "regular feature of almost all farming societies" (Fuller, 1991; Bartlett, 1986; Bessant, 2000). More than half of U.S. farm operators now work off the farm.[6] Moreover, off-farm income appears to smooth out household income flows (Mishra and Goodwin, 1997; Mishra and Sandretto, 2002), and most farmers view off-farm employment as a permanent rather than a temporary or transitional (into or out of farming) pursuit (Ahearn and El-Osta, 1993).[7] Farm operators in a 1982 survey felt that full-time farming provided inadequate income (91 percent of the respondents), and that farm income was risky (70 percent) and offered no fringe benefits such as pensions and health insurance (55 percent). Capital and land constraints were considered less important disadvantages to full-time farming (42 and 30 percent) (Barlett, 1991). More

Table 1
Operator and spouse hours worked on and off farm,1996-2004

Item	1996	2000	2004
Operator hours worked:			
On farm	1,525	1,433	1,547
Off farm	830	1,011	1,022
Total	2,355	2,443	2,596
Spouse hours worked:			
On farm	366	337	877
Off farm	690	751	809
Total	1,056	1,089	1,686

Sources: 1996: Hoppe (2001, p. 29); 2000: Mishra et al. (2002, p. 50); 2004: ARMS data.

[5]Across all farms, operators earned 64 percent of all household off-farm earned income in 2001, spouses earned close to 33 percent, and other members earned 3 percent (O'Donoghue and Hoppe, 2005).

[6]There are, however, some issues regarding the definition of a farm. Since the USDA definition of a farm is not adjusted for inflation, the number of small operations that get defined as farms may increase over time, which may also increase the share of operators working off the farm.

[7]A minority of farmers (18.4 percent of the total in 1987) may be considered as a transitional group, i.e., full-time farmers who worked off farm because they faced heavy losses and high debts. Some of these farmers expected to return to full-time farming when their financial situation was resolved (Bartlett, 1991). Moreover, using agricultural census data spanning 1982 to 1997, ERS researchers identified 644 (out of over 5,000) small part-time farms that managed to grow into large commercial operations. These farms are called emergent adaptive farms (EAF). Off-farm work provided financial support during the early years of the typical EAF, but EAF operators spent more time on farm activities as their businesses expanded: 35 percent of EAF operators worked at least 200 days off the farm in 1987, but that share declined to 16 percent by 1997 (Newton, 2005).

recently, the 2004 ARMS asked operators and spouses to list the two main reasons for seeking off-farm work. The primary reason given by 35-50 percent of the operators and 44-63 percent of the spouses (depending on farm size and occupation of the farm operator) was "to increase income" of the farm household. Other reasons cited were to obtain fringe benefits (such as health insurance) and personal satisfaction (Covey et al., 2005).

So most operators and spouses report working off farm primarily to increase income for the farm household, but how was the additional income used? Contrary to conventional wisdom, most farm operators and spouses did not work off the farm to directly support their farm business. USDA surveys indicate reasons unrelated to the farm business, from buying groceries to funding a retirement account (Hoppe, 2001).

Farmers and spouses hold a variety of off-farm jobs, but especially in private businesses (54.1 percent of operators with off-farm jobs), self-employment (22.3 percent), and government (16.0 percent). Only 3.3 percent worked on another farm (Mishra et al., 2002). Spouses with off-farm work are most likely to be employed in the private sector (55.1 percent) and government (28.4 percent), with less than 1 percent working on another farm.

Opportunity Cost of Labor for Farm Operators

Opportunity cost is an important economic concept that measures the economic cost of an action or decision in terms of what is given up (opportunity forgone) to carry out that action. In the case of farm labor, for example, the opportunity cost of labor for the operator (or spouse) labor is often measured in terms of the wage that the operator (or spouse) can obtain working off farm. As the United Nations' Economic Commission for Europe notes: "In conventional accounting systems, 'unpaid' family labour does not usually appear as an explicit cost of production. Consequently, there is no explicit 'wage' paid to the labour that the farmer and his family [contribute to] production."

Farm household labor is a critical input in agricultural production. In the corn/soybean-producing States, farm household members provide more than 80 percent of all labor hours.[8] A significant proportion of those labor hours is not valued directly in the marketplace (e.g., through wages). Studies have estimated the opportunity costs of farm labor by using predicted off-farm wages (El-Osta and Ahearn, 1996).

Alternatively, a simplified approximation of the opportunity cost of labor for farm operators and their spouses can be obtained directly from ARMS data. The (nominal) opportunity costs for corn/soybean operators and spouses appear not to have increased over 1996-2000. The cost for the operator ($21.07 per hour for 2000) appears to run about 20 percent higher than that of the spouse, and both are higher than the actual wage rate for hired farm labor.[9]

It is also interesting to compare the opportunity cost of labor for corn/soybean farmers with those of dairy farmers. The cost for U.S. dairy farmers in 2000 was econometrically estimated at $27.58 per hour for oper-

[8]Corn/soybean-producing States are defined as those that account for most of the U.S corn and soybean production. States included are Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin.

[9]The opportunity cost of labor varies with the farm's region, size, and specialization, the operator's human capital (education and experience); and household characteristics (El–Osta and Ahearn). In addition, opportunity cost estimates may vary with the characteristics of the labor markets, the methodology used, and data sources.

ators (30 percent higher than for corn/soybean farmers) and $19.36 for spouses (18 percent higher) (Lovell and Mosheim, 2005). Given that labor requirements in dairy production are high and inflexible (El-Osta and Ahearn), dairy farmers likely require a higher "wage" to work off the farm than farmers working in other enterprises.

Table 2
Opportunity cost of labor for corn/soybean farm operators and spouses, and actual hired farm wage rate, 1996-2000

Year	Operator	Spouse	Hired
		Dollars per hour	
1996	22.88	17.87	7.42
1997	26.72	19.06	8.01
1998	22.14	18.77	8.30
1999	22.19	17.96	8.67
2000	21.07	17.47	8.99

Source: ERS estimates based on ARMS data for corn/soybean States analyzed (Nehring, Fernandez-Cornejo, and Banker, 2005).

Off-Farm Income and Farm/Household Characteristics

Like their nonfarm counterparts, many farm households are dual career. While operators and spouses across all sizes and typologies work off-farm or manage nonfarm businesses, the level of off-farm income varies with farm size, region, farm type, and the human capital of operators and spouses.

Off-Farm Income and Farm Size

Off-farm income varies inversely with farm size; operators of smaller farms have higher off-farm incomes, both earned and total.[10] Farm households with gross farm sales less than $10,000 had total off-farm income averaging nearly $74,000 in 2004 ($54,600 of which was earned), while households with farm sales between $250,000 and $499,999 had total off-farm income averaging about $45,000 ($33,200 earned) (table 3). While off-farm income constitutes the largest component of farm household income on average, its share decreases with farm size. For farms with gross sales higher than $250,000 (less than 8 percent of U.S. farms), off-farm income is no longer the largest component of household income (table 4).

Off-farm household income earned by the operators is more variable across farm sizes ($27,500 for operators of smaller farms versus less than $10,000 for operators of the largest farms) than that earned by spouses (between $12,000 and $14,000 across all sizes in 2004). Off-farm income earned by other household members averages around $1,000.

To a large extent, the inverse relationship between off-farm earned income and farm size is due to greater off-farm employment (and more hours worked off the farm) by operators of smaller farms. More than 55 percent of operators with farm sales less than $100,000 reported off-farm hours in 2004 versus 20 percent or less for operators of farms with sales above $250,000 (table 4). On the other hand, off-farm income earned by farm operators who work off-farm does not vary much with size, averaging $47,000 for operators of the smallest farms and $39,000 for operators of the largest farms.

[10]Smaller farms represent a very large share of farm population but a small share of the farm sales. For example, about 44 percent of the farms have sales less than $10,000 and more than 80 percent of the farms have sales below $100,000 (table 3). This distribution, however, is dependent on the definition of farm. In the United States, a farm is currently defined, for statistical purposes, "as any place from which $1,000 or more of agricultural products were sold or normally would have been sold during the year under consideration." (USDA, 2005).

Table 3
Off-farm household income by farm size, 2004

Farm sales	Share of farms	Income earned by the operator	Income earned by the spouse	Income earned by other members	Off-farm business income	Total earned income	Unearned income	Total off-farm income
	Percent				*Dollars*			
$9,999 or less	43.7	27,457	14,756	1,219	11,209	54,641	19,392	74,033
$10,000-$99,999	40.7	24,295	13,095	1,142	9,889	48,422	19,549	67,971
$100,000-$249,999	7.9	11,074	14,722	1,158	8,493	35,445	11,467	46,913
$250,000-$499,999	4.2	7,559	13,439	836	11,404	33,238	11,633	44,870
$500,000-$999,999	2.0	7,790	12,816	1,110	8,371	30,086	21,991	52,077
$1,000,000 or more	1.5	4,898	12,017	612	10,744	28,271	12,811	41,082
All farms	100.0	23,318	13,943	1,156	10,402	48,818	18,461	67,279

Source: 2004 ARMS data.

Table 4
Farm household income by farm size, 2004

Farm size (annual sales)	Number of farms	Share of farms income	Total household farming	Income from income	Share of farm	Off-farm income
	Number	*Percent*	*Dollars*	*Dollars*	*Percent*	*Dollars*
$9,999 or less	901,333	43.7	71,155	-2,878	-8.9	74,033
$10,000-$99,999	838,912	40.7	72,061	4,091	11.7	67,971
$100,000-$249,999	162,782	7.9	80,912	33,999	18.9	46,913
$250,000-$499,999	86,087	4.2	124,386	79,516	23.4	44,870
$500,000-$999,999	41,424	2.0	168,844	116,766	16.5	52,077
$1,000,000 or more	30,284	1.5	411,266	370,184	38.3	41,082
All farms	2,060,822	100.0	81,480	14,201	100.0	67,279

Farm size (annual sales)	Earned off-farm income	Share of operators reporting off-farm hours	Off-farm earned income by operators who worked	Off-farm earned income of operators	Share of spouses reporting off-farm hours	Off-farm income earned by spouses	Off-farm earned income of spouses who worked off-farm
	Dollars	*Percent*	*Dollars*	*Dollars*	*Percent*	*Dollars*	*Dollars*
$9,999 or less	54,641	58.7	27,457	46,775	44.1	14,756	33,460
$10,000-$99,999	48,422	55.5	24,295	43,775	45.5	13,095	28,780
$100,000-$249,999	35,445	31.1	11,074	35,608	54.4	14,722	27,063
$250,000-$499,999	33,238	20.4	7,559	37,054	45.2	13,439	29,732
$500,000-$999,999	30,086	18.6	7,790	41,882	44.8	12,816	28,607
$1,000,000 or more	28,271	12.6	4,898	38,873	37.2	12,017	32,304
All farms	48,818	52.1	23,318	44,756	45.4	13,943	30,711

Source: 2004 ARMS data.

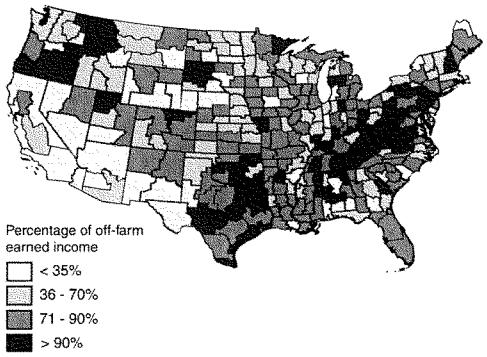
The inverse relationship between farm size and off-farm work still holds after controlling for other factors, as demonstrated econometrically by many researchers (Lass et al., 1989, 1991; Yee et al., 2004). In addition, Goodwin and Bruer (2003) and Fernandez-Cornejo et al. (2005) showed that the inverse relationship holds for both operator and spouse.

Time allocation between onfarm and off-farm activities by household members appears to be the underlying reason for the inverse relationship between farm size and off-farm work. This relationship appears to be valid regardless of the sequence in which time is allocated between farm and off-farm work. As Olfert (1984) notes, it may be the case that farmers choose farm size and type after knowing the time commitments required by an off-farm job, or farmers may choose the type and amount of off-farm work after taking into account the nature of the labor requirements on the farm.[11]

Off-Farm Income and Farm Location

Off-farm employment also varies geographically, with widely differing shares of off-farm income (to total income) even within States (fig. 2). In general, high ratios of off-farm earned income to total income are exhibited in the four regions—the Northeast, Appalachian, Southern Plains, and Northwest—where job opportunities tend to be highest or farm income lowest. In many cases, one family member may focus on the farm operation while the spouse and children work off the farm. In other situations, the farm operation may be a side job and a refuge from urban stress. The supply of off-farm labor has been shown to be positively related to urban proximity (Lass et al., 1991). Moreover, Gardner (2001) found that farmers' income growth is inversely related to the rural share of a State's population. Gardner observed that this finding supports Schultz's (1950) hypothesis that "a larger presence of nonfarm people in a State is good for

Figure 2
The importance of off-farm income by ASD*, 2001 (off-farm earned income/total income)



*ASD = Agricultural Statistics District.
Source: 2001 ARMS data.

[11]The tradeoff between time spent in onfarm and off-farm activities also manifests itself in Conservation Reserve Program (CRP) participation. Boisvert and Chang (2006) found empirical evidence that a household's decision to participate in the CRP and to work off the farm are made jointly rather than independently. Participation in off-farm work with higher wages provides an incentive for operators to work less on the farm and to take land out of production and commit it to the CRP. As a result, participation in the CRP and off-farm work increase household income.

the growth of farmers' incomes, because it increases their off-farm earnings opportunities and increases the demand for the goods and services that farmers produce." This may be particularly true for agricultural States with large urban populations such as Texas, where off-farm opportunities increase near one of that State's four major cities—Dallas-Fort Worth, Houston, San Antonio, and Austin.

Off-Farm Income, Type of Enterprise, and Human Capital

Off-farm work is less likely on farms with labor-intensive enterprises such as dairy (Leistritz et al., 1985) and other livestock (Lass et al., 1991; Goodwin and Bruer, 2003). Moreover, dairy farmers who do work off the farm tend to require higher "wages" (the opportunity cost of labor is higher) to work off farm than farmers working in other enterprises.

The supply of off-farm labor has also been shown to be positively related to human capital such as education and experience of the operator and spouse (Lass et al., 1991). The number of children is positively associated with off-farm employment for farm men, but the association is negative for farm women. More children may imply more need for additional income but also additional child care at home.

Off-Farm Work, Scale and Scope Economies, and Efficiency

The importance of off-farm income to all U.S. farmers is widely acknowledged, and the relative dedication to off-farm work is related to farm size, location, specialty, and operator characteristics. However, is off-farm work actually helping farm households in general, and those operating small farms in particular, to improve their economic performance? Since scale and scope economies, as well as economic efficiency, are key concepts used by economists to examine economic performance, this section introduces those concepts as they relate to off-farm work.

A farm is said to have economies of scale (or increasing returns to scale) if the average cost of production declines as output (scale of production) increases (see box, p. 4). This decline in per-unit costs as output increases suggests that smaller farms can achieve cost advantages by becoming larger. The concept of economies of scale is an important one. For example, farms with lower average costs are better able to cope with higher input prices (Kumbhakar, 1993). On the other hand, increasing returns to scale in production may lead to consolidation of firms with potential effects on competition (Hallam, 1991).

With multiple outputs, the measurement of scale economies becomes more complicated. In addition to changes in costs that occur as output expands, there are also changes in costs due to the product mix (Hallam, 1991). If it is cheaper to produce several outputs in one operation than it is to produce them in separate operations, economies of scope are said to occur (see box, p. 14).

Off-Farm Work and Scale Economies

We estimated the scale economies for corn and soybean farms for 1996-2000, from an input perspective. Scale economies both at the farm level (the measure traditionally reported) and at the household level (including off-farm income-generating activities as an output) are considered. At the farm level, the elasticity of scale ranges from about 0.56 for smaller farms (gross sales less than $100,000), to about 0.8 for the larger farms (sales greater than $500,000) (table 5). This means that to support a 10-percent increase in outputs, smaller farms would require a 5.6-percent increase in all inputs, while larger farms would require an 8-percent increase in inputs. Thus, the greater scale economies available for smaller operations provide a major inducement to increase farm size (compared with the larger farms whose scale elasticities are closer to 1).

However, at the household level, with off-farm income-generating activities included, the scale economies available are lower (scale elasticity is closer to 1; that is, closer to constant returns to scale). Thus, the scale elasticity is higher for all sizes, ranging from 0.73 to 0.96 (table 5). So for smaller farms, a 10-percent increase in all outputs requires a 7.3-percent increase in inputs, while larger farms require a 9.6-percent increase in inputs.[12] More importantly, the difference between the scale elasticities at the household and farm levels is larger for the smaller farms (30 percent)

[12]The scale elasticity increases (moves closer to constant returns to scale) when off-farm income is included because of the theoretical relationship between scale and scope economies in multi-product firms: "the presence of scope economies 'magnifies' the extent of overall economies of scale beyond what would result from a simple weight sum of product specific economies of scale" (Baumol et al., 1982).

Table 5
Scale economies for corn/soybean farms, 1996-2000

Farm type[1]	Gross sales	Elasticity of scale: Farm level (Excluding off-farm income)	Elasticity of scale: Household level (Including off-farm income)
Farming occupation/ lower sales	< $100,000	0.56	0.73
Farming occupation/ medium sales	$100,000-$249,999	0.74	0.88
Large family farms	$250,000-$499,999	0.77	0.94
Vary large family farms	>$500,000	0.80	0.96
All farms		0.66	0.83

[1]Excluding limited-resource farms and retirement/residential farms. Limited-resource farms are small farms with gross sales less than $100,000, total farm assets less than $150,000, and total operator household income less than $20,000. Limited-resource farmers may report farming, a nonfarm occupation, or retirement as their major occupation. Retirement/residential farms are small farms whose operators report they are retired or engaged in a major occupation other than farming) (Hoppe et al., 1999)

Source: Nehring et al., 2005.

than for the larger farms (around 20 percent). Thus, households operating smaller farms may compensate for the scale disadvantages of their farm business activities with the advantages of off-farm income-generating activities. This advantage may also support the notion that integrated farm and nonfarm labor markets are enabling many small farms to survive and flourish to an extent not thought possible three decades ago (Gardner, 2005).

Off-Farm Work and Economies of Scope

Scope economies measure the cost savings due to simultaneous production of outputs relative to the cost of separate production (see box, p. 14). The concept of economies of scope is useful in assessing the advantages of output diversification. Given the importance of off-farm income to U.S. farm households, scope economies may be expanded to include as output any income-generating activities on or off the farm (household-level scope economies) (see appendix 1).[13] Our estimates for corn and soybean farms show substantial household-level scope economies, 0.24 on average. This means that farm households engaged in off-farm income-generating activities together with the production of traditional farm outputs have cost savings of 24 percent relative to carrying out those activities separately.[14] The cost savings are likely to arise from the sharing of managerial expertise (of the operator and spouse) between onfarm and off-farm activities. Economic evaluations of the farm business alone, then, provide an incomplete view because they exclude off-farm activities, which are an important means of output diversification.

[13]Farms that produce the two output groups separately are those that either produce conventional outputs and no off-farm income or else generate off-farm income but no conventional outputs. While our sample includes farm households that produce conventional outputs with no off-farm activities, it technically does not include households with zero traditional outputs. However, the sample does include many farm households with very small revenues from traditional outputs because, for statistical purposes, in the U.S., a farm is currently defined "as any place from which $1,000 or more of agricultural products were sold or normally would have been sold during the year under consideration" (USDA, 2005). We consider five outputs (corn, soybeans, other crops, livestock, and operator/spouse off-farm labor) and five inputs (hired labor, operator labor, spouse labor, miscellaneous inputs, and pesticides). The method of calculating scope economies, as well as the underlying cost function, is shown in appendix 1.

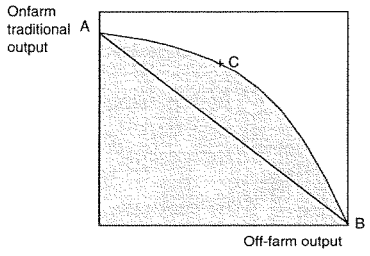
[14]This result is valid on the average, not necessarily for all the corn/soybean farms studied. For example, it is not likely to be valid for the largest farms in the sample (whose operators are less likely to work off the farm, table 4). As shown in appendix 1, the underlying cost function is a function of the output quantities (and, thus, gross sales), and so are scope economies. The values reported here are calculated at the means of the sample.

Scope Economies

Scope economies measure the total cost savings due to simultaneous production of outputs relative to the costs of separate production (appendix 1). Given scope economies, it is less costly to produce several outputs in one operation than to produce each output in separate operations (or joint production in one operation generates more output than separate production in two different operations using the same resources). An often-cited example of scope economies is fast food outlets, where savings are obtained by sharing storage, cooking facilities, and customer service in the production of many food products. In general, scope economies may arise from the presence of public inputs or from sharing of imperfectly divisible quasi-fixed inputs in the production of different goods (Fernandez-Cornejo et al., 1992). In our context, farm households achieve scope economies by diversifying or pursuing off-farm activities in addition to the onfarm production of traditional commodities.

To illustrate the possible advantages of "producing" onfarm and off-farm outputs in a farm household, we may use the example of a production possibilities curve (often used in economics). When the production possibilities curve (ACB) is shaped as in the figure, it is advantageous to produce onfarm and off-farm outputs together. As the figure shows, total output produced by a farm household at point C (a combination of onfarm and off-farm outputs) is higher than output produced either at A or B (or a linear combination of both, line AB) while using the same amount of resources.

Diagram of a production possibilities curve



Scope economies for farm households are likely to arise from the sharing of managerial expertise (and its many components, such as accounting and information processing skills, sales expertise, administrative and technical know-how, etc.) between onfarm and off-farm activities.[15] The expertise of many farm operators and/or their spouses is used in off-farm jobs in private businesses and Government, and in self-employment (Mishra et al., 2002). A USDA survey shows that the largest share of off-farm work done by operators and their spouses is accounted by work in executive, administrative, and managerial positions, service occupations, administrative support, and sales (Covey et al., 2004).

[15]As is well known, diminishing marginal labor productivity is a determinant in the allocation of labor between onfarm and off-farm activities. In addition, labor requirements for crop production are often concentrated in very few months of the year. Thus, the marginal productivity of managerial labor for the rest of the year is often very low or negligible (Olfert, 1984).

Off-Farm Work and Efficiency

Technical efficiency measures how well a farm transforms inputs into outputs given the technology at its disposal (Kumbhakar and Lovell, 2000). Efficiency is of great importance to prevent the waste of resources. Technically inefficient farmers fail to produce the maximum attainable output with the amount of inputs used, and therefore can increase output with the existing level of inputs and available technology.

Two types of technical efficiency are examined here: traditional (farm-level) technical efficiency of the farm business in the production of commodities; and technical efficiency at the household level, which considers both on- and off-farm activities.[16]

Efficiency of the Farm Business

Kumbhakar et al. (1989) examined the effect of off-farm income on farm-level efficiency for dairy farmers. They reasoned that the larger the off-farm component of the operator's income, the less time the operator would spend managing the farm, eroding farm-level efficiency. Indeed, they found that farm-level efficiency of Utah dairy farmers in 1985 was negatively related to off-farm income and that the negative effect was strongest for the smallest farms, which had the largest off-farm incomes.[17] Fernandez-Cornejo (1992) calculated that the farm-level technical efficiency of vegetable farms in Florida was negatively related to off-farm work carried out by the operator. Similar results were obtained by Aigner et al. (2003) for the farm-level efficiency of U.S. corn farmers using 2001 data.

More recently, Goodwin and Mishra (2004) analyzed the relationship between farm-level efficiency and off-farm labor supply. With data collected from 7,699 farms in USDA's 2001 Agricultural Resource Management Survey (ARMS), they used gross cash income (appendix table 1) over total variable costs as an operational measure of farm-level economic efficiency. Greater participation in off-farm labor markets was shown to be significantly associated with lower farm-level efficiency. An additional 1,000 hours engaged in off-farm work would tend to lower the farm-level efficiency ratio by 0.17 with respect to the mean, which was $1.93 of cash farm income per dollar of variable cost. This effect, while not large, was statistically and economically significant. Such findings support the notion hypothesized by Smith (2002) that off-farm work may hinder "smart farming" and confirm a negative relationship between farming efficiency and the supply of labor to off-farm employment. As theory predicts, more efficient farmers are less likely to work off the farm, reflecting the higher opportunity cost for their labor. Furthermore, the statistical tests performed by Goodwin and Mishra suggest that off-farm labor supply and farm-level efficiency are jointly determined.[18]

Household-Level Efficiency

Rather than estimating the influence of off-farm work on the efficiency of the farm business, we estimated the household-level technical efficiency (including on- and off-farm activities), compared it with farm-level effi-

[16]We have adopted the terminology of "farm-level" and "household-level" efficiency following a recent publication by Chavas et al. (2005). Our earlier terminology (as used in Nehring et al., 2005) was less transparent.

[17]In a subsequent article, Kumbhakar (1993) showed that lower efficiency is the main reason that small farms are less profitable than medium and large farms: another reason being their higher returns to scale (lower scale economies).

[18]There is a two-way relationship between the two variables rather than a cause-and-effect relationship (in economic jargon, each variable is endogenous to the other).

ciency, and examined how those efficiencies vary with farm size. The technique used in this research isolates the best-practice farm within any size class, and measures technical efficiency by how close other farms are, on average, to the best-practice farms, which are assigned a technical efficiency equal to 1 and said to be on the "frontier." [19]

At the farm level, technical efficiencies of corn/soybean farms increase with size from 0.87 to 0.93 (table 6).[20] However, technical efficiencies at the household level (when off-farm income is included) are higher (around 0.95) and the measures of technical efficiency do not vary across size groups. Moreover, while the beneficial effect of off-farm income occurs at all sizes, it is stronger for smaller farms, whose household-level efficiency levels are comparable with the farm-level efficiencies of the larger farms. This suggests that small corn/soybean farmers have adapted to shortfalls in farm-level efficiency by increasing off-farm income.

Also, the higher household-level efficiencies are consistent with the positive scope economies found. Both findings reflect the more efficient use of resources at the household level, particularly the use of managerial labor (operator and spouse) shared between onfarm and off-farm activities.

Moreover, as Smith (2002) observes, as farm operators and other household members engage in off-farm activities, they have less time available for farm management. This may inhibit their adoption of management-intensive agricultural innovations and lead to less efficient farming.

Table 6
Technical efficiency of corn/soybean farms, 1996-2000

		Technical efficiency scores	
Farm type[1]	Gross sales ($)	Farm level (excluding off-farm income)	Household level (including off-farm income)
Farming occupation/ lower sales	< $100,000	0.87	0.95
Farming occupation/ medium sales	$100,000-$249,999	0.91	0.95
Large family farms	$250,000-$499,999	0.91	0.95
Very large family farms	> $500,000	0.93	0.95
All farms		0.91	0.95

[1]Excluding limited-resource and retirement/residential farms.

Source: Nehring et al., 2005

[19]The analysis uses several econometric techniques, including the estimation of an input distance function and stochastic frontier estimation (appendix 1; Nehring et al., 2005) to estimate technical efficiency at the farm (excluding off-farm income-generating activities) and at the household level (including off-farm income-generating activities). Data used were 1995-2003 survey data of corn/soybean farms from 10 States (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin), that account for most U.S corn and soybean production.

[20]A farm unit with an efficiency score of 0.8 is said to be 80 percent as efficient as the farms on the 'frontier," i.e., the best performing farms in the data set.

Off-Farm Work and the Adoption of Agricultural Innovations

Technological change has been acknowledged as a critical component of productivity and economic growth (Solow, 1994; Griliches, 1995). The rapid adoption and diffusion of new technologies in U.S. agriculture has sustained growth in agricultural productivity and ensured an abundance of food and fiber (Huffman and Evenson, 1993). Technological innovations and their adoption have also changed the way farm households regard employment choices (Binswanger, 1974, 1978). Labor-saving technologies, in particular, have allowed farm household members to increase income by seeking off-farm employment (Mishra et al., 2002).[21]

While profitability (i.e., the extent of yield increases and/or reduction in input costs from an innovation relative to the costs of adoption and current management practices) plays a key role in technology adoption, most studies acknowledge that heterogeneity among farms and farm operators often explains why not all farmers adopt an innovation in the short or long run (Batte and Johnson, 1993; Feder and Umali, 1993; Khanna and Zilberman, 1997; Lowenberg-DeBoer and Swinton, 1997; Rogers, 1961, 1995) (see box, "Factors Influencing Technology Adoption").

Still, assessments of technology adoption using the traditional economic tools pioneered by Griliches (1957) have proven insufficient to explain differing adoption rates for many recent agricultural innovations. The standard measures of farm (accounting) profits, such as net returns (to management), give an incomplete picture of economic returns because they usually exclude the value of management time (Smith, 2002). For example, herbicide-tolerant soybeans were rapidly adopted despite showing no significant advantage in net returns over conventional soybeans. On the other hand, adoption of technologies such as integrated pest management (IPM) has been rather slow despite explicit economic and environmental advantages (Fernandez-Cornejo and McBride, 2002; Smith, 2002). This led to the hypothesis that adoption is driven by "unquantified" advantages, such as simplicity and flexibility, which translate into reduced managerial intensity, freeing time for other uses. An obvious use of managers' time is off-farm employment.

Off-Farm Work as a Factor in Early Studies of Technology Adoption

Early studies of technology adoption viewed off-farm income as influencing adoption of "conservation" practices by providing "supplemental income" to finance conservation expenditures (Blase, 1960). Ervin and Ervin (1982), on the other hand, argued that "off-farm income could reflect the need for supplemental income for family living expenses and essential farm production expenses other than conservation and less time to implement and maintain unfamiliar practices." Survey results on farmers' motivation to seek off-farm income and their view of such employment as permanent rather than temporary, suggest that motivation is closer the view of Ervin and Ervin.

[21]Off-farm employment was also facilitated by economic growth in the nonfarm economy, improved infrastructure (communications and transportation), as well as education level of farm household members (Banker and MacDonald, 2005).

Factors Influencing Technology Adoption

Rural sociologists recognized early that essential differences among farmers can explain why they do not adopt an innovation at the same time. In addition, the characteristics (perceived or real) of an innovation are widely known to influence the adoption decision (Rogers, 1995; Batz et al., 1999). Economists and sociologists have made extensive contributions to the literature on the adoption and diffusion of technological innovations in agriculture (e.g., Griliches, 1957, Feder et al., 1985; Rogers, 1962, 1995). Such research typically focuses on the long-term extent of adoption and the factors that influence the adoption decision.

Farm Structure/Size
A basic hypothesis regarding technology transfer is that the adoption of an innovation will tend to take place earlier on larger farms than on smaller farms. Just et al. (1980) show that, given the uncertainty and the fixed transaction and information costs associated with innovations, there may be a critical lower limit on farm size that prevents smaller farms from adopting. As these costs increase, the critical size also increases. It follows that innovations with large fixed transaction and/or information costs are less likely to be adopted by smaller farms. However, Feder et al. (1985) point out that lumpiness of technology can be offset by the emergence of a service sector (i.e., custom service or consultant). Disentangling farm size from other factors hypothesized to influence technology adoption has been problematic. Feder et al. (1985) caution that farm size may be a surrogate for other factors, such as wealth, risk preferences, and access to credit, scarce inputs, or information. Moreover, access to credit is related to farm size and land tenure because both factors determine the potential collateral available to obtain credit.

Human Capital
The ability to adapt new technologies for use on the farm clearly influences the adoption decision. Most adoption studies attempt to measure this trait through operator age, formal education, or years of farming experience (Fernandez-Cornejo et al., 1994). More years of education and/or experience is often hypothesized to increase the probability of adoption whereas increasing age reduces the probability. Factors inherent in the aging process or the lowered likelihood of payoff from a shortened planning horizon over which expected benefits can accrue would be deterrents to adoption (Barry et al., 1995; Batte and Johnson, 1993). Younger farmers tend to have more education and are often hypothesized to be more willing to innovate.

Risk and Risk Preferences
In agriculture, the notion that technological innovations are perceived to be more risky than traditional practices has received considerable support in the literature. Many researchers argue that the perception of increased risk inhibits adoption (Feder et al., 1985). Hiebert (1974) and Feder and O'Mara (1981) show that uncertainty declines with learning and experience. Innovators and other early adopters are believed to be more inclined to take risks than are the majority of farmers.

Tenure
While several empirical studies support the hypothesis that land ownership encourages adoption, the results are not unanimous and the subject has been widely debated (e.g., Feder et al., 1985). For example, Bultena and Hoiberg (1983) found no support for the hypothesis that land tenure has a significant influence on adoption of conservation tillage. The apparent inconsistencies in the empirical results are due to the nature of the innovation. Land ownership is likely to influence adoption if the innovation requires investments tied to the land. Presumably, tenants are less likely to adopt these types of innovations because the benefits of adoption will not necessarily accrue to them.

Credit Constraint, Location, and Other Factors
Any fixed investment requires the use of own or borrowed capital. Hence, the adoption of a non-divisible technology, which requires a large initial investment, may be hampered by lack of borrowing capacity (El-Osta and Morehart, 1999). Location factors—such as soil fertility, pest infestations, climate, and availability or access to information—can influence the profitability of different technologies across different farms. Heterogeneity of the resource base has been shown to influence technology adoption and profitability (Green et al., 1996; Thrikawala et al., 1999). Irrigation may also influence adoption. Irrigation generally increases yields and profitability and reduces production risk. However, irrigation may also increase risk; for example, it may encourage certain pest populations (Harper and Zilberman, 1989). Contractual arrangements for the production/marketing of the crop are also believed to influence the adoption of certain technologies. Contracts often specify the acreage to be grown or quantity and quality of product to be delivered and may also require the application of certain inputs and practices.

McNamara et al. (1991) used empirical evidence from peanut producers to conclude that integrated pest management (IPM) required substantial time for management and that off-farm employment may present a constraint to IPM participation. Fernandez-Cornejo et al. (1994), Fernandez-Cornejo (1996, 1998), and Fernandez-Cornejo and Jans (1996) found similar results for vegetable and fruit producers. Wozniack (1993) considered livestock feeding innovations and showed that off-farm wage income was inversely related to the likelihood of early adoption and acquiring information.[22] More recent survey results show that operators of high-sales, large, and very large farms—which depend on farm revenues more (and therefore less on off-farm employment) than smaller farms—tend to adopt more management-intensive technologies. For example, around 18 percent of the operators of larger farms adopted precision farming in 1998. In contrast, only 3 percent of the operators of smaller farms (who worked more off-farm hours) adopted precision farming (Hoppe, 2001).

[22]Measures used included off-farm income as a percentage of total household income (Ervin and Ervin, 1982) or days (or hours) per year that the operator worked off-farm (Fernandez-Cornejo, 1996, 1998; Fernandez-Cornejo and Jans, 1996).

Weaknesses of Early Studies

While insightful, early studies failed to model the interaction of technology adoption and off-farm employment decisions based on the underlying economic theory and consistent with farmers' optimization behavior. Rather, they simply included some measure of off-farm work as one explanatory variable in the adoption decision. Early studies also had some econometric problems, such as not accounting for simultaneity of the off-farm work and adoption decisions and the possibility of self-selection (see appendix 2).[23] Finally, earlier studies did not examine the relationship between technology adoption and household income from farm and off-farm sources.

[23]Self-selection occurs because farmers are not assigned randomly into groups (e.g., farmers that work off farm or not, adopt or not) but make the choices themselves. Therefore, group members may be systematically different, and these differences may manifest themselves in farm performance and could be confounded with differences due purely to working off farm (or adoption). This situation, called self-selection, may bias the statistical results unless it is corrected (appendix 2).

Modeling the Interaction Between Off-Farm Work and Adoption Decisions

To address these issues, we examine the interaction of off-farm income-earning activities and adoption of four agricultural technologies (see box, p. 22) of varying managerial intensity, including herbicide-tolerant crops (Fernandez-Cornejo and Hendricks, 2003; Fernandez-Cornejo et al., 2005), precision agriculture (Fernandez-Cornejo and Southern, 2004), conservation tillage (Fernandez-Cornejo and Gregory, 2004), and Bt (*Bacillus thuringiensis*) corn (Fernandez-Cornejo and Gregory, 2004). We also estimated empirically the relationship between the adoption of these innovations and farm household income from onfarm and off-farm sources.

For this purpose, we expanded the agricultural household model to include the technology adoption decision together with the off-farm work participation decisions by the operator and spouse (appendix 2).[24] We developed an econometric model to examine the interaction of off-farm work and adoption of agricultural technologies, as well as the impact of technology adoption on farm household income (from onfarm and off-farm sources) after controlling for such interaction (appendix 2). The model used data from nationwide surveys of corn and soybean farms in 2000-2001.

[24]The agricultural household model (Singh et al., 1986; Huffman, 1980, 1991; Lass et al., 1989; Lass and Gempesaw, 1992; Kimhi, 1994, 2004) combines in a single framework all important economic decisions of the farm household.

We hypothesize that adoption of managerial-saving technologies (such as herbicide-tolerant (HT) soybeans) frees up management time for use elsewhere (notably off-farm employment), leading to higher off-farm income. On the other hand, managerially intensive technologies (such as precision agriculture) would result in less time available for off-farm activities, leading to lower off-farm income.

It is also possible that farmers already working off farm may be more disposed to adopt managerial-saving technologies. This may lead to additional off-farm work and result in even higher off-farm income. Similarly, farmers who are working off farm may be reluctant to adopt managerially intensive technologies.[25]

In either case, we anticipated that adoption of managerial-saving technologies would be associated with higher off-farm income and adoption of managerially intensive technologies would be related to lower off-farm income. (In this report, we show only the empirical validity of the relationship, but not the direction of the causality.)

A two-stage econometric estimation method was used to estimate the empirical model (appendix 2). The first stage, the decision model, examines the factors influencing off-farm work participation and technology adoption decisions. The second stage is used to estimate the relationship between technology adoption and household income.

Technology Adoption and Off-Farm Income

We find that the relationship between the adoption of herbicide-tolerant (HT) soybeans and *off-farm* household income is positive and statistically significant (table 7). The elasticity of off-farm household income with respect to the probability of adoption of HT soybeans (calculated at the mean) is +1.59.[26] That is, after controlling for other factors, a 15.9-percent increase in off-farm household income is associated with a 10-percent increase in the probability of adopting HT soybeans. The adoption of HT soybeans is also positively and significantly associated with total household income (from off-farm and onfarm sources). A 9.7-percent increase in total household income is associated with a 10-percent increase in the probability of adopting of HT soybeans. On the other hand, adoption of herbicide-tolerant soybeans did not have a significant relationship with household income from farming (table 7).

Results for adoption of conservation tillage are similar to those obtained for HT soybeans, but of a lesser magnitude (table 7). Controlling for other factors, the association between the adoption of conservation tillage and off-farm household income is positive and statistically significant (elasticity +0.98). An increase in *off-farm* household income of 9.8 percent is associated with a 10-percent increase in the probability of adopting conservation tillage. The association of adoption of conservation tillage and total household income (including both off-farm and onfarm sources) is positive and statistically significant. The elasticity of total household income with respect to the probability of adopting conservation tillage is +0.46.

[25]As Olfert observes: "Given the nature of nonfarm jobs, where commitments to specific timeframes are frequently more precise than is the case in farming, it is possible that a nonfarm job receives first priority in the allocation of time with farm production undertaken as a second priority." However, Olfert adds: "It may also be the case that the decision regarding time allocation to farm and nonfarm work is made simultaneously or that the off-farm employment decision influences the type and size of farm that is optimal. Farm enterprises that are less demanding in their commitments may be chosen to permit nonfarm employment. Knowing the time commitments required by the nonfarm job, the farm size and type will be organized to accommodate that schedule. Similarly, given the nature of labour requirements on the farm, a choice will be made about the type and amount of nonfarm work."

[26]Results are expressed in terms of elasticity—the percent change in a particular variable (e.g., household income) relative to a small percent change in adoption of the technology from current levels, controlling for other factors. The elasticity results can be viewed in terms of the aggregate change in a particular variable (across an entire agricultural region or sector) relative to aggregate increases in adoption (as more and more producers adopt the technology). However, in terms of a typical farm —that has either adopted or not— the elasticity is usually interpreted as the (marginal) farm-level change associated with an increase in the probability of adoption, away from a given, or current, level of adoption. As shown in appendix 2, the regression model controls for farm location and typology, operator age, education, and experience, number of children, price of the crop, a measure of specialization on soybean/corn production, a measure of the extent of livestock operations, farm size, and proxies for local labor market conditions.

Table 7
Elasticities of farm household income with respect to the probability of adopting technologies of differing managerial intensity

Elasticity of	With respect to adoption of: Yield monitors	Bt corn[1]	Conservation tillage	Herbicide-tolerant (HT) soybeans
Onfarm household annual income	0[2]	0[2]	0[2]	0[2]
Off-farm household annual income	-0.84	0[2]	+0.98	+1.59
Total household annual income	0[2]	0[2]	+0.46	+0.97

[1]Bt = Bacillus thuringiensis)
[2]Statistically insignificant underlying coefficient. The underlying coefficients and their standard errors are shown in appendix 2.

On the other hand, the relationship between the adoption of yield monitors (an important component of precision agriculture) and off-farm household income is negative and statistically significant (elasticity = -0.84) when we control for other factors. That is, a decrease in off-farm household income by 8.4 percent is associated with a 10-percent increase in the probability of adopting yield monitors. Adoption of yield monitors did not have a statistically significant association with either farm household income or total household income. These results are quite different from those for HT soybeans and conservation tillage. This empirical evidence suggests that yield monitoring techniques are management-intensive compared with the other two technologies, which spare management time.

Finally, the relationship between the adoption of Bt corn with either off-farm or onfarm household income was not statistically significant, indicating that Bt corn may be managerially neutral.

These results are consistent with anecdotal evidence (see box "Selected Agricultural ...") that herbicide-tolerant soybeans save managerial time because of the simplicity and flexibility of weed control. Conservation tillage is also believed to save managerial labor, but to a lesser degree than HT soybeans. Our results for yield monitoring are also consistent with anecdotal evidence that precision farming techniques in general are managerially using. Before the commercial introduction of Bt corn in 1996, most farmers accepted yield losses rather than incur the expense and uncertainty of chemical control. For those farmers, the use of Bt corn was reported to result in yield gains rather than pesticide savings, and savings in managerial time were small.

Selected Agricultural Technologies and Their Managerial Intensity

Herbicide-tolerant (HT) soybeans contain traits that allow them to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds. This allows farmers to use more effective postemergent herbicides, expanding weed management options (Gianessi and Carpenter, 1999). The most common herbicide-tolerant crops are resistant to glyphosate, a herbicide effective on many species of grasses, broadleaf weeds, and sedges. Adoption of HT soybeans has risen rapidly since commercial availability in 1996. HT soybean use rose quickly to about 17 percent of U.S. soybean acreage in 1997 and reached 87 percent in 2005 (Fernandez-Cornejo and McBride, 2002; USDA, NASS, 2003).

Herbicide-tolerant soybeans save managerial time because of the relative simplicity and flexibility of the weed control program. The herbicide-tolerant technology allows growers to apply one herbicide product over the soybean crop at any stage of growth, instead of using several herbicides, to control a wide range of weeds "without sustaining crop injury" (Gianessi and Carpenter, 1999). In addition, using HT soybeans is said to make harvest easier (Duffy, 2001).

Conservation tillage is defined as "any tillage or planting system that maintains at least 30 percent of the soil surface covered by residue after planting" (Conservation Technology Information Center, 2004). It includes no-till, ridge-till, and mulch-till techniques. The impact of conservation tillage in controlling soil erosion and soil degradation is well documented (Edwards, 1995; Sandretto, 1997). By leaving substantial amounts of residue evenly distributed over the soil surface, conservation tillage reduces soil erosion by wind/water, increases water infiltration and moisture retention, and reduces surface sediment and chemical runoff. Adoption of conservation tillage was estimated at 2 percent of planted acreage in 1968 and grew fastest during 1975-85, reaching nearly 28 percent in 1985 (Schertz, 1988). It reached about 37 percent of planted acreage in 2002 (Conservation Technology Information Center, 2004). Conservation tillage is used primarily to grow corn, soybeans, small grains, and cotton.

Conservation tillage is believed to save managerial labor (Sandretto, 1997; USDA, 1998). While it is accepted that adoption of conservation tillage leads to labor savings, its slower rate of adoption compared with HT crops may be because the managerial savings are less.

Bt crops carry the gene from the soil bacterium *Bacillus thuringiensis* (Bt) and are able to produce proteins that are toxic to certain insects. Bt corn, originally developed to control the European corn borer, was planted on 35 percent of corn acreage in 2005, up from 24 percent in 2002. The recent upswing may be due to the commercial introduction in 2003/04 of a new Bt corn variety that is resistant to the corn rootworm.

Before the commercial introduction of Bt corn in 1996, chemical pesticide use was often not profitable to control the European corn borer (ECB) and timely application was difficult (Fernandez-Cornejo and Caswell, 2006). Many farmers accepted yield losses rather than incur the expense and uncertainty of chemical control. For those farmers, the use of Bt corn resulted in yield gains rather than pesticide savings, and managerial time savings were minimal.

Precision agriculture (PA) is often characterized as a suite of technologies used to monitor and manage subfield spatial variability. It includes, for example, global positioning systems, grid soil sampling, yield monitors, and input applicators that can vary rates across a field (Daberkow et al., 2002). These technologies can be used independently or as a package of technologies that includes, for example, the use of grid soil sampling, a variable-rate input applicator, and a yield monitor. PA has been growing relatively slowly. Yield monitors, which provide farmers site-specific data to allow them to vary input application and production practices, are the most extensively adopted PA component. Yield monitors were used in about 33 percent of total corn acreage in 2001 and in about 25 percent of soybean acreage. Adoption of other components of PA is even slower. Adoption of variable-rate applicators reached just 10 percent of corn acreage for fertilizer and 3 percent for pesticides or seeds in 2001 (Daberkow et al., 2002).

Unlike herbicide-tolerant soybeans, which provide savings in management time (and therefore allow operators to obtain higher income from off-farm activities), yield monitors (and precision agriculture in general) are generally believed to be human capital-intensive (Griffin at al., 2004).

Conclusions

As onfarm and off-farm activities compete for scarce managerial time in U.S. farm operator households, economic decisions (including technology adoption and other production decisions) are likely to shape and be shaped by time allocation within the household. Time allocation decisions are usually not measured directly, but their outcomes, such as onfarm and off-farm income, are observable.

Our research finds that the farm-level efficiency of farm households decreases as off-farm activities increase. Smaller farms, which average the highest off-farm incomes, obtain the lowest farm-level efficiencies. These results support the hypothesis that farm operators who devote more time to off-farm activities have less time to manage the farm. However, examining efficiency from a wider perspective, we find that household-level efficiency (including off-farm income-generating activities) is higher across all farm sizes than farm-level efficiency alone. Moreover, the beneficial effect of off-farm income is higher for smaller farms. In fact, farm households operating small farms achieve efficiency levels comparable to those operating larger farms when off-farm income is included. These results, therefore, suggest that farm households operating small farms have adapted to shortfalls in farming performance by increasing off-farm income.

By including off-farm income-generating activities in the household output portfolio (in addition to the traditional farm products), many farm households, especially those operating smaller farms, are able to enhance diversification. The advantages of such diversification, measured by the household-level economies of scope, are substantial. These results suggest that off-farm employment may enhance onfarm diversification, especially for households operating small farms.

The economic inducement of smaller farms to increase their size (measured by the economic concept of scale economies) is reduced when we include off-farm income. Household-level scale economies (which include off-farm income-generating activities) are closer to constant returns to scale than are farm-level scale economies (which only consider the farm business). However, the beneficial effect of off-farm activities in improving scale economies is more pronounced for households operating smaller farms. These findings provide a different way of measuring the role of off-farm work in improving the economic condition of farm households, particularly those operating small farms.

The adoption of agricultural innovations is also linked to off-farm income through managerial time. For example, the adoption of managerial time-saving technologies is significantly related to higher off-farm household income for U.S. corn/soybean farmers, after controlling for other factors. On the other hand, managerially time-intensive technologies are associated with significantly lower off-farm income.

In a broader sense, these findings confirm the tradeoff between time spent on farm and off-farm activities or, in economic terms, the substitution of economies of scope (derived from engaging in multiple income-generating activities, on and off the farm) for economies of scale.

A number of implications follow. Each of these implications reinforces the importance of understanding farmers' decisions in the context of the farm household rather than the farm operation alone. First, our research provides empirical confirmation of Smith's suggestion that households operating small farms, which lack economies of scale, are more likely to devote time to off-farm opportunities, more likely to adopt management-saving technologies (like herbicide-tolerant crops), and less likely to adopt management-intensive technologies (such as integrated pest management).

The relationship between off-farm work and economic performance also suggests that a farm household's dependence on off-farm income has an effect on the distributional consequences of government policies. Government policies affecting agriculture—such as conservation, research and development, extension, and farm support—may affect farm households differently depending on the relative importance of onfarm and off-farm income-generating activities. Thus, the consequences of government policies depend on the diversity of U.S. farm households, particularly regarding their income sources. For example, a policy promoting the adoption of management-intensive agricultural techniques (such as IPM) may not be fully effective unless it takes into consideration the demands in managerial time imposed by IPM adoption.

This research also has implications for private agricultural research and development (R&D). While innovators often base their economic evaluations of returns to R&D on the expected profitability of potential innovations for farmers (i.e., the extent of yield increases and/or input cost reduction resulting from an innovation relative to the costs of adoption and current management practices), this report shows that there is an important additional element to be included in such evaluations: the value of management time.

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Appendix 1—Economies of Scale and Scope and Technical Efficiency

This discussion uses two different but related methodologies and data sets and follows the analysis described in Nehring et al., 2005. First, using 1996-2000 survey data, we use an input distance function to estimate scale economies and technical efficiency, and compare these performance measures at the farm and household levels. Second, using 2000 survey data, we set up a multi-activity cost function to analyze labor allocation decisions within the farm operator household and estimate scope economies. We interpret off-farm income-generating activities as outputs, along with corn, soybeans, livestock, and other crops. For both estimations, we use detailed survey information of the farm operator household from USDA's Agricultural Resource Management Survey (ARMS).

Economies of Scale and Technical Efficiency

The analysis of production structure and performance requires representing the underlying multi-dimensional (input and output) production technology. This may be formalized by specifying a transformation function, $\boldsymbol{T(X,Y,R)=0}$, which summarizes the production frontier in terms of an input vector $\boldsymbol{X}$, an output vector $\boldsymbol{Y}$, and a vector of external production determinants $\boldsymbol{R}$. This information on the production technology can also be characterized via an input set, $L(\boldsymbol{Y,R})$, representing the set of all X vectors that can produce Y, given the exogenous factors $\boldsymbol{R}$.

An input distance function (denoted by superscript I) identifies the least input use possible for producing the given output vector, defined according to $L(\boldsymbol{Y,R})$:

$$(1) \quad D^{I}(\boldsymbol{X,Y,R}) = Max\{\rho : (x/\rho) \in L(\boldsymbol{Y,R})\}.$$

This multi-input, input-requirement function allows for deviations from the frontier. It is also conceptually similar to a cost function, if allocative efficiency is assumed, in the sense that it implies minimum input or resource use for production of a given output vector (and thus, implicitly, costs). However, it does so in a primal/technical optimization or efficiency context, with no economic optimization implied.

For the farm-level model, the $\boldsymbol{Y}$ vector contains Y_1 = crops (corn, soybeans, and other crops), Y_2 = livestock, and, for the household-level model, Y_1^* = crops and livestock, and Y_2^* = off-farm income-generating activities, as farm "outputs." With Y_2^* included, one might think of $\boldsymbol{Y}$ as a multi-activity rather than a multi-output vector. The components of X are defined as X_1 = land (LD), X_2 = hired labor (L), X_3 = operator labor (including hours worked off-farm)(K), X_4 = spouse labor (including hours worked off-farm) (E), X_5 = capital (F), and X_6 = materials (M).

The scale economies measure may be computed from the estimated model via derivatives or scale elasticities: $-\varepsilon_{DIY} = -\Sigma_m \partial \ln D^{I}(\boldsymbol{X,Y},t)/\partial \ln Y_m = \varepsilon_{XIY}$ for M outputs Y_m (similar to the treatment in Baumol et al. (1982) for a multiple-output cost model, and consistent with the output distance function

formula in Färe and Primont (1995). However, the inverse measure is more comparable to the cost literature, where the extent of increasing returns or scale economies is implied by the shortfall of the measure from 1. Again, this measure is based on evaluation of (scale) expansion from a given input composition base.

The distance function can be approximated by a translog functional as follows:

$$(2)\quad \ln D^{I}_{it}/X_{1,it} = \alpha_0 + \alpha_t\, t + \Sigma_m \alpha_m \ln X^{*}_{mit} + 0.5\, \Sigma_m \Sigma_n \beta_{mn} \ln X^{*}_{mit} \ln X^{*}_{nit} + \Sigma_k \alpha_k \ln Y_{kit} + 0.5\, \Sigma_k \Sigma_l \alpha_{kl} \ln Y_{kit} \ln Y_{lit} + \Sigma_k \Sigma_m \delta_{km} \ln Y_{kit} \ln X^{*}_{mit},$$

or

$$(3)\quad -\ln X_{1,it} = \alpha_0 + \alpha_t\, t + \Sigma_m \alpha_m \ln X^{*}_{mit} + 0.5\, \Sigma_m \Sigma_n \beta_{mn} \ln X^{*}_{mit} \ln X^{*}_{nit} + \Sigma_k \alpha_k \ln Y_{kit} + 0.5\, \Sigma_k \Sigma_l \alpha_{kl} \ln Y_{kit} \ln Y_{lit} + \Sigma_k \Sigma_m \delta_{km} \ln Y_{kit} \ln X^{*}_{mit} - \ln D^{I}_{it},$$

where i denotes farm and t time period. This functional relationship, which embodies a full set of interactions among the $\boldsymbol{X}$, $\boldsymbol{Y}$ and t arguments of the distance function, can more succinctly be written as: $-\ln X_{1,it} = TL(\boldsymbol{X}/X_1, \boldsymbol{Y}, t) = TL(\boldsymbol{X}^*, \boldsymbol{Y}, t)$.

The input distance function is well-suited to measure technical efficiency. For empirical estimation of technical efficiency, we append a symmetric error term, v, to equation (3) and change the notation "$-\ln D^{I}_{it}$," to "u." The resulting function (with the subscripts it suppressed for notational simplicity) is: $-\ln X_1 = TL(\boldsymbol{X}^*, \boldsymbol{Y}, t) + v - u$, where the term $(-u)$ may be interpreted as inefficiency (as technical efficiency measures the distance from the frontier). This method is known as a stochastic frontier production function, where output of a firm is a function of a set of inputs, inefficiency (- u) and a random error v (Aigner et al., 1977; Greene, 1995, 1997, 2000).

To estimate the function, we used Coelli's FRONTIER program (Coelli, 1996), based on the error components model of Battese and Coelli (1992). Since -u represents inefficiency, the technical efficiency scores are given by $\exp(-u) = D^{I}(\mathbf{X}^*, \mathbf{Y}, t)$. If a firm is not technically inefficient (the firm is on the frontier), u is equal to 0 and its technical efficiency score is 1.

In the absence of genuine panel data, repeated cross-sections of data across farm typologies are used to construct a pseudo-panel data set (see Deaton, 1985; Heshmati and Kumbhakar, 1992; Verbeek and Nijman, 1993). The pseudo-panels are created by grouping the individual observations into a number of homogeneous cohorts, demarcated on the basis of their common observable time-invariant characteristics, such as location and ERS farm typology. The subsequent economic analysis then uses the cohort means rather than the individual farm-level observations. ERS farm typology categories are summarized in Nehring et al. (2005). The resulting pseudo panel data set consists of 13 cohorts by State, for 1996-2000, measured as the weighted mean values of the variables to be analyzed. There are a total of 650 annual observations (130 per year), summarizing the activities of 1,934 farms in 1996, 3,890 in 1997, 2,311 in 1998, 3,201 in 1999, and 2,394 in 2000.

Economies of Scope

When a firm produces more than one output, there is a qualitative change in the production structure that makes the concept of economies of scale developed for a single output insufficient. For multiproduct firms, production economies may arise not only because the size of the firm is increased but also due to advantages derived from producing several outputs together rather than separately. Thus, more than one measure is necessary to capture the economies (or diseconomies) related to the scale of operation (volume of output) and the economies related to the scope of the operation (composition of output or product mix). The concepts of economies of scale and scope for multiproduct firms have been developed by Panzar and Willig (1977, 1981) and Baumol et al. (1982). They have been used in agriculture by Akridge and Hertel (1986) and Fernandez-Cornejo et al. (1992).

Economies of scope measure the cost savings due to simultaneous production relative to the cost of separate production. In general, scope economies occur when the cost of producing all products together is lower than producing them separately.

Formally, consider a partition of the output set N into two (disjoint) groups T and N-T. Let Y_T, Y_{N-T} be the output quantity (subvector) of each of the two groups and Y_N (or simply Y) the output vector, which consists of all the outputs. The respective cost functions $C(Y_T)$, $C(Y_{N-T})$ give the minimum cost of producing the two output groups separately, and $C(Y_N)$ denotes the minimum cost of producing them together (Nehring et al., 2005).

The degree of economies of scope *(SC)* relative to the (output) set T is defined as:

$$(1) \qquad SC = [C(Y_T)+C(Y_{N-T}) - C(Y_N)] / C(Y_N)$$

where SC will be positive if there are economies of scope and negative if there are diseconomies of scope. In our case, we consider the first subset of the partition to include the four conventional outputs (corn, soybeans, other crops, and livestock), $N=\{1,2,3,4\}$ and the second subset the non-conventional off-farm income-generating activities, $N\text{-}T=\{5\}$.

Farms that produce the two output groups separately are those that either produce conventional outputs with no off-farm activities or else those with off-farm work but no conventional outputs. While the sample includes farm households that produce conventional outputs and no off-farm activities, it technically does not include household with zero traditional outputs. However, the sample does include many farm households with very small revenues from traditional outputs because, for statistical purposes, a U.S. farm is currently defined as "any place from which $1,000 or more of agricultural products were sold or normally would have been sold during the year under consideration." (USDA, 2005).

The well-developed restricted cost function is used to estimate the scope economies. Consider n outputs, m variable inputs, and s fixed inputs and other exogenous factors such as location or weather proxies; $\mathbf{Y} = (Y1,...Yn)'$

denotes the vector of outputs, $\boldsymbol{X} = (X1,...Xm)'$ denotes the vector of variable inputs, $\boldsymbol{Z} = (Z_1,...Zs)'$ is the vector of non-negative quasi-fixed inputs and other (exogenous) factors, and $\boldsymbol{W} = (W1,...Wm)'$ denotes the price vector of variable inputs. The restricted profit function is defined by:

$$C(W,Y,Z) = Min\ [W'X : \in T]. \tag{3}$$

Under the usual assumptions on the technology (production possibilities set T), the restricted cost function is well defined and satisfies the usual regularity conditions.

Using a normalized quadratic variable cost function, which can be viewed as a second-order Taylor series approximation to the true cost function, we obtain:

$$C(W,Y,Z) = a_0 + (a'b'c')\begin{bmatrix} W \\ Y \\ Z \end{bmatrix} = 1/2(W'Y'Z')\begin{bmatrix} B & E & F \\ E & C & G \\ F & G & D \end{bmatrix}\begin{bmatrix} W \\ Y \\ Z \end{bmatrix} \tag{4}$$

where $\boldsymbol{W}$ is a vector of normalized variable input prices, a_0 is a scalar parameter, and $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$ are vectors of constants of the same dimension as $\boldsymbol{W}$, $\boldsymbol{Y}$, and $\boldsymbol{Z}$. The parameter matrices $\boldsymbol{B}$, $\boldsymbol{C}$, and $\boldsymbol{H}$ are symmetric and of the appropriate dimensions. Similarly, $\boldsymbol{E}$, $\boldsymbol{F}$, and $\boldsymbol{G}$ are matrices of unknown parameters.

Using Shephard's lemma, we obtain the demand functions for variable inputs which is estimated together with the cost function. We consider five outputs Y (corn, soybeans, other crops, livestock, and operator and spouse off-farm labor), five inputs X (hired labor, operator labor, spouse labor, miscellaneous inputs, and pesticides), and use the pesticides price as the *numeraire*. In addition the cost function is specified with two exogenous factors (Nehring et al., 2005).

The normalized quadratic variable cost function and the four cost-share equations are estimated in an iterated seemingly unrelated regression (ITSUR) framework using data for year 2000. The adjusted R^2's were 0.99 for the quadratic cost function, 0.26 for the hired labor input, 0.21 for the operator labor equation, 0.30 for the spouse labor equation, and 0.60 for the miscellaneous inputs equation. However, 48 percent of coefficients for the joint estimates are significant at the 10 percent level.

The own-price effects for the inputs exhibit the expected negative signs. The own-price effect for hired labor is significant at the 10-percent level, while the own-price effects for operator labor and spouse labor are not significant in this cross-section. The own price elasticity of demand for hired labor is highly elastic, with a value of -2.62. In contrast, the own- price elasticities of demand for operator and spouse labor are highly inelastic, with values of -0.105 and -0.283. These results, however, are not directly comparable with cost function studies in the literature that do not include off-farm income-generating activities as an output.

Appendix 2—Incorporating Technology Adoption in the Farm Household Model

The Theoretical Framework

This model combines in a single framework the technology adoption and off-farm work decisions by the operator and spouse and follows the analysis developed by Fernandez-Cornejo et al. (2005). The model expands the farm household model offered by Huffman (1991) with several additions to allow for technology adoption. According to the agricultural household model, farm households maximize utility U subject to income, production technology, and time constraints. Household members receive utility from goods purchased for consumption G, leisure (including home time) $L = (L_o, L_s)$ for the operator and the spouse, and from factors exogenous to current household decisions, such as human capital $H = (H_o, H_s)$, and other factors Ψ (including household characteristics and weather). Thus:

(1) $Max\ U = U(G, \mathbf{L}, \mathbf{H}, \Psi)$

Subject to the constraints:

(2) $P_g G = P_q Q - \mathbf{W}_x \mathbf{X}' + \mathbf{W}\mathbf{M}' + A$ (income constraint)

(3) $Q = Q[X(\Gamma), \mathbf{F}(\Gamma), \mathbf{H}, \Gamma, \mathbf{R}],\ \Gamma \geq 0$ (technology constraint)

(4) $\mathbf{T} = \mathbf{F}(\Gamma) + \mathbf{M} + \mathbf{L}, \mathbf{M} \geq 0$ (time constraint)

where P_g and G denote the price and quantity of goods purchased for consumption; P_q and Q represent the price and quantity of farm output; $\mathbf{W}_x$ and $\mathbf{X}$ are the price and quantity (row) vectors of farm inputs; $\mathbf{W} = (W_o, W_s)$ represents off-farm wages paid to the operator and spouse; $\mathbf{M} = (M_o, M_s)$ is the amount of time working off-farm by the operator and spouse; $\mathbf{F} = (F_o, F_s)$ is the amount of time working on the farm by the operator and spouse; A is other income, including income (from interest, dividends, annuities, private pensions, and rents) and government transfers (such as Social Security, retirement, disability, and unemployment); $\mathbf{R}$ is a vector of exogenous factors that shift the production function, and $\mathbf{T} = (T_o, T_s)$ denotes the (annual) time endowments for the operator and spouse. The production function is concave and has the usual regularity characteristics. Some technologies offer simplicity and flexibility that translate into reduced management time, freeing time for other uses. In these cases, the amount of time working on the farm by the operator and the spouse $\mathbf{F}$ (and possibly the use of other farm inputs $\mathbf{X}$) is a function of Γ, the adoption intensity (extent of adoption) of the technology. A technology-constrained measure of (cash) household income is obtained by substituting (3) into (2) (Huffman, 1991):

(5) $P_g G = P_q Q[X(\Gamma), \mathbf{F}(\Gamma), \mathbf{H}, \Gamma, \mathbf{R}] - \mathbf{W}_x \mathbf{X}(\Gamma)' + \mathbf{W}\mathbf{M}' + A$

The first order conditions for optimality (Kuhn-Tucker conditions) are obtained by maximizing the Lagrangian expression $\mathcal{L}$ over $(G, \mathbf{L})$ and minimizing it over the Lagrange multipliers (λ, μ), where $\mu = (\mu_0, \mu_s)$:

(6) $\mathcal{L} = U(G, \mathbf{L}, \mathbf{H}, \Psi) + \lambda \{ P_q Q[\mathbf{X}(\Gamma), \mathbf{F}(\Gamma), \mathbf{H}, \Gamma, \mathbf{R}] - \mathbf{W}x\,\mathbf{X}(\Gamma)' + \mathbf{W}\,\mathbf{M}' + A - P_g G \} + \boldsymbol{\mu} [\mathbf{T} - \mathbf{F}(\Gamma) - \mathbf{M} - \mathbf{L}]$

The off-farm participation and adoption decisions may be obtained from the following Kuhn-Tucker conditions:

(7) $\partial\mathcal{L}/\partial\mathbf{X} = \lambda (P_q\, \partial Q/\partial\mathbf{X} - \mathbf{W}_x) = \mathbf{0}$

(8) $\partial\mathcal{L}/\partial F = \lambda\, Pq\, \partial Q/\partial F - \boldsymbol{\mu} = \mathbf{0}$

(9) $\partial\mathcal{L}/\partial\Gamma = \lambda[P_q[(\partial Q/\partial X)(d\mathbf{X}/d\Gamma)' + (\partial Q/\partial\mathbf{F})(d\mathbf{F}/d\Gamma)' + \partial Q/d\Gamma] - \mathbf{W}_x (d\mathbf{X}/d\Gamma)'\} - \boldsymbol{\mu}\,(d\mathbf{F}/d\Gamma)' \leq 0,$

$\Gamma \geq 0, \quad \Gamma \cong \partial\mathcal{L}/\partial\Gamma = 0$

(10) $\partial\mathcal{L}/\partial\mathbf{M} = \lambda\, \mathbf{W} - \boldsymbol{\mu} \leq 0, \quad \mathbf{M} \geq 0, \quad \mathbf{M}(\lambda\, \mathbf{W} - \boldsymbol{\mu}) = 0$

(11a, b) $\partial\mathcal{L}/\partial G = U_G - P_g\, \lambda = 0, \; \partial\mathcal{L}/\partial\mathbf{L} = \mathbf{U}_L - \boldsymbol{\mu} = \mathbf{0}$

(12) $P_q\, Q[\mathbf{X}(\Gamma), \mathbf{F}(\Gamma), \mathbf{H}, \Gamma, R] - \mathbf{W}_x\, \mathbf{X}(\Gamma)' + \mathbf{W}\mathbf{M}' + A - P_g\, G = 0$

(13) $\mathbf{T} - \mathbf{F}(\Gamma) - \mathbf{M} - \mathbf{L} = \mathbf{0}$

where U_L, U_G are the partial derivatives of the function U. Without loss of generality, both the operator and spouse are assumed to have positive optimal hours of leisure and farm work, i.e., equation (8) and (11b) are equalities.

The off-farm participation decision conditions for the operator and the spouse may be obtained from the optimality conditions for off-farm work, equation (10), together with equations (8) and (11b):

(14) $\mathrm{W} \leq \boldsymbol{\mu}/\lambda = \mathrm{P_q}\, \partial Q/\partial F$

where $\boldsymbol{\mu}/\lambda$ is equal to the marginal rate of substitution between leisure and consumption goods (from equations 11a and 11b) and $P_q\ \partial Q/\partial F$ represents the value of the marginal product of farm labor for the operator and the spouse. Examining the components of (14), $W_i < \boldsymbol{\mu}_i/\lambda$ (strict inequality) indicates that the total time endowment for the operator ($i = o$) or spouse ($i = s$) is allocated between farm work and leisure; optimal hours of off-farm work are zero (corner solution), i.e., $M_i^* = 0$. On the other hand, if $W_i = \boldsymbol{\mu}_i/\lambda$, optimal hours of off-farm work may be positive ($M_i^* > 0$) and $W_i = \boldsymbol{\mu}_i/\lambda = P_q\ \partial Q/\partial F_i$ (interior solution) (Lass et al., 1989; Huffman, 1991; Kimhi, 1994; Huffman and El-Osta, 1997). In this case, the value of the marginal product of farm labor is equal to the off-farm wage rate.[27]

When an interior solution for $\boldsymbol{M}$ occurs, equations (7) and (8) can be solved together, independently of the rest of the Kuhn-Tucker conditions, to obtain the demand functions for onfarm labor, i.e., the optimal production and consumption decisions can be separated since the off-farm wage determines the value of the operator's and spouse's time ($\mathrm{W} = \boldsymbol{\mu}/\lambda$) (Huffman and Lange, 1989; Huffman, 1991).[28]

[27]The marginal value of time of the farm operator (or spouse) when all his/her time is allocated to farm work and leisure and none is allocated to off-farm work ($P_q\ \partial Q/\partial F_i\,|_{Mi=0}$) represents the shadow value of farm labor and is called the reservation wage for off-farm work for the operator (i = o) or spouse (i = s). In this context, the operator (or spouse) will work off-farm when his/her reservation wage is less than the anticipated off-farm wage rate and will not work off-farm otherwise. Assuming that both the operator and spouse face wages that are dependent on their marketable human capital characteristics ξi, local labor market conditions, and job characteristics Ω, but not on the amount of off-farm work (Huffman and Lange, 1989; Huffman, 1991; Tokle and Huffman, 1991), the off-farm market labor demand functions are $W_i = W_i(\xi i, \Omega), (i = o, s)$.

[28]Moreover, when an interior solution occurs, from (10), (11a), and (11b) we obtain $\mathbf{U}_L/U_G = \mathbf{W}/P_g$; that is, the marginal rate of substitution between consumption goods and leisure is equal to the ratio of the wage rate and the price of consumption goods.

The demand function for onfarm labor is then $\boldsymbol{F}^*=F(\boldsymbol{W}, \boldsymbol{W}_x, P_q, \boldsymbol{H}, \Gamma, R)$ and the demand for purchased farm inputs $\boldsymbol{X}^* = X(\boldsymbol{W}, \boldsymbol{W}_x, P_q, \boldsymbol{H}, \Gamma, \boldsymbol{R})$. These optimal input demand functions are substituted in the production function to obtain the supply of farm output $Q^* = S(\boldsymbol{W}, \boldsymbol{W}_x, P_q, \boldsymbol{H}, \Gamma, \boldsymbol{R})$ and the maximum net household income may be expressed as:

$$(15) \qquad NI^* = P_q\, S(\boldsymbol{W}, \boldsymbol{W}_x, P_q, \boldsymbol{H}, \Gamma, \boldsymbol{R}) - \boldsymbol{W}_x \boldsymbol{X}^{*\prime} + \boldsymbol{W}\boldsymbol{M}' + A$$

Solving jointly equations (10), (11), and (15) we obtain the demand for leisure $\boldsymbol{L}^* = L(\boldsymbol{W}, P_g, NI^*, \boldsymbol{H}, \Psi, \boldsymbol{T})$ and for consumption goods $G = G(\boldsymbol{W}, P_g, NI^*, \boldsymbol{H}, \Psi, \Gamma, \boldsymbol{T})$. The supply function for off-farm time is obtained by substitution of the optimal levels of leisure hours and farm work hours (Huffman, 1991):

$$(16) \qquad \boldsymbol{M}^* = \boldsymbol{T} - \boldsymbol{F}^* - \boldsymbol{L}^* \;= M(\boldsymbol{W}, \boldsymbol{W}_x, P_q, Pg, NI^*, \boldsymbol{H}, \Psi, \Gamma, \xi i, \Omega, \boldsymbol{R}, \boldsymbol{T})$$

Finally, a reduced-form expression of total household income is obtained by:

$$(17) \qquad NI^* = NI(\boldsymbol{W}_x, P_q, P_g, A, \boldsymbol{H}, \Psi, \Gamma, \boldsymbol{R}, \boldsymbol{T})$$

As Huffman (1991) notes, when optimal hours of off-farm work hours for the operator or the spouse are zero, the decision process is not recursive and production and consumption decisions must be made jointly. In this case, the arguments for the reduced-form expression of household income are the same as those in (17) but exclude the exogenous variables related to the job characteristics and labor marketability.

The technology adoption decision condition is obtained from the optimality conditions, equation (9) and equations (8) and (11b), noting that the expression in brackets in (9) is the total derivative $dQ/d\Gamma$. Thus, we obtain:

$$(18) \qquad Pq\, dQ/d\Gamma \; - \boldsymbol{W}_x\, (d\boldsymbol{X}/d\Gamma)' - (\boldsymbol{\mu}/\lambda)(d\boldsymbol{F}/d\Gamma)' \leq 0$$

But from (11a) and (11b) $\boldsymbol{\mu}/\lambda = P_g\, (U_L/U_G)$; then:

$$(19) \qquad P_q\, dQ/\Gamma \; - \boldsymbol{W}_x\, (d\boldsymbol{X}/d\Gamma)' - P_g\, (U_L/U_G)(d\boldsymbol{F}/d\Gamma)' \leq 0$$

The left-hand-side of this expression may be interpreted as the marginal benefit of adoption $P_q\, dQ/d\Gamma$ minus the marginal cost of adoption, which includes the marginal cost of the production inputs $\boldsymbol{W}_x\, (d\boldsymbol{X}/d\Gamma)'$ and the marginal cost of the farm work $P_g\, (\boldsymbol{U}_L/U_G)(d\boldsymbol{F}/d\Gamma)'$ (of the operator and the spouse) brought about by adoption (could be negative if adoption saves managerial time), valued at the marginal rate of substitution between leisure and consumption goods (which, when off-farm work hours are positive, equals the off-farm wage rate). It will not be optimal to adopt if the inequality is strict (corner solution), wherein the marginal benefit of adoption falls short of the marginal cost of adoption. An interior solution for the optimal extent of adoption will occur when the equality is strict or when the value of the marginal benefit of adoption is equal to the marginal cost of adoption.

Given the cross-sectional nature of the data, one can use the implicit function theorem to derive expressions for off-farm labor supply for farm operator and spouse and technology adoption (which affects off-farm labor

supply of farm operators and spouses) that are functions of wages, prices, human capital, nonlabor income, and other exogenous factors. These factors are replaced in reduced-form representations of labor supply and adoption by observable farm, operator, and household characteristics, including human capital. The "ambient variables" (family size, access to urban areas), which might affect the productive capacity of the farm operator and the spouse, are also included. The following section outlines the empirical model and estimation method used to conduct the analysis.

Empirical Model

A two-stage econometric model is specified. The first stage, the decision model, examines the off-farm work participation and the technology adoption decisions. The second stage is used to estimate the impact of adoption on household income.

A simplified "reduced form" approach is followed (Goodwin and Holt, 2002; Goodwin and Mishra, 2004) to specify the empirical model, rather than explicitly estimating a structural model of labor supply. In this approach, the reduced form of the decision model is obtained by specifying the endogenous variables ($\boldsymbol{M}$, $\boldsymbol{F}$, Q_g, $\boldsymbol{X}$) in terms of the exogenous variables, including $\boldsymbol{W}_x$, P_q, P_g, $\boldsymbol{H}$, Ψ, ξ_i, Ω, $\boldsymbol{R}$, $\boldsymbol{T}$. Equation (14), implied by the Kuhn-Tucker conditions, is central to the off-farm work decision of the operator and the spouse and equation (19) is central to the adoption decision. Thus, considering a first-order approximation (linear terms) and adding the stochastic terms, the empirical representation of the decision model, which includes the off-farm participation of the operator (20a) and spouse (20b), and the technology adoption decision (20c), is:

(20a) $$\boldsymbol{\beta}_o \boldsymbol{Z}_o' + \varepsilon_o \leq 0$$

(20b) $$\boldsymbol{\beta}_s \boldsymbol{Z}_s' + \varepsilon_s \leq 0$$

(20c) $$\boldsymbol{\beta}_a \boldsymbol{Z}_a' + \varepsilon_a \leq 0$$

where the (row) vectors Z_o, $\boldsymbol{Z}_s$, and $\boldsymbol{Z}_a$ include all the factors or attributes influencing linearly the off-farm participation (operator and spouse) and adoption decisions, and $\boldsymbol{\beta}_o$, $\boldsymbol{\beta}_s$, and $\boldsymbol{\beta}_a$ are vectors of parameters. Assuming that the stochastic disturbances are normally distributed, each of these equations may be estimated by probit. However, because the disturbances (ε_o, ε_s, ε_a) are likely to be correlated, univariate probit equations are not appropriate. Bivariate probit models have been used to model the off-farm employment decisions by the operator and spouse (Huffman and Lange, 1989; Lass et al., 1989; Tokle and Huffman, 1991). Since the decisions to work off farm and the technology adoption decision may be related, all three decisions are modeled together in a multivariate probit model (Greene, 1997). Formally, [ε_o, ε_s, ε_a] ~ trivariate normal (TVN) [0,0,0; 1,1,1; ρ_{12},ρ_{13},ρ_{23}], with variances ρ_{ij} ($i = j$) equal to 1 and correlations ρ_{ij} ($i \neq j$) where $i, j = 1$,2,3.

The joint estimation of three or more probit equations was computationally unfeasible until recently because of the difficulty in evaluating high-order multivariate normal integrals. Over the past decade, however, the estimation

has been made possible with Monte Carlo simulation techniques (Geweke et al., 1994; Greene, 1997).

The vector $\boldsymbol{Z}_i$ includes (i) farm factors, such as farm size and complexity of the operations; (ii) human capital (operator age/experience and education); (iii) household characteristics (such as the number of children); (iv) off-farm employment opportunities, which will depend on the farms' accessibility to urban areas and the change in the rate of unemployment in nearby urban areas; (v) farm typology; and (vi) government payments.[29] The factors or attributes influencing adoption, included in the vector $\boldsymbol{Z}_a$, are farm factors, human capital, farm typology, a proxy for risk (risk-averse farmers are less likely to adopt agricultural innovations), and crop/seed prices.

[29]Following Goodwin and Holt (2002), some prices are not included in our empirical models since prices are approximately constant across households when data consist of cross-sectional observations taken at a point in time. We did include some prices, like the price of soybeans, but its coefficient was statistically insignificant.

The second stage, the income impact model, provides estimates of the impact of adoption on household income after controlling for other factors. The empirical representation of this model—based on equation (17), the reduced-form expression of household income—is $NI^* = NI(\boldsymbol{W}_x, P_q, P_g, A, \boldsymbol{H}, \Psi, \Gamma, \boldsymbol{R}, \boldsymbol{T})$.

After linearizing this reduced form, separating out explicitly the adoption indicator variable, and appending a random disturbance å, assumed to be normally distributed, we have:

$$NI^* = \boldsymbol{\theta V}' + \alpha I + \varepsilon \tag{21}$$

where NI^* represents household income; $\boldsymbol{V}$ is a (row) vector of observable explanatory variables that may influence household income (other than technology adoption) such as prices, human capital, and "ambient variables" (family size, access to urban areas) that may affect the productive capacity of the farm operator and the spouse; I is an indicator variable for adoption ($I=1$ if adoption takes place and $I=0$ otherwise); and $\boldsymbol{\theta}$ and α are appropriately dimensioned parameters. The impact of adoption on household income is measured by the estimate of the parameter α. However, as noted by Stefanides and Tauer (1999), if α is to measure the impact of adoption on income of a representative farm, farmers should be randomly assigned among adopter and nonadopter categories. This is not the case, since farmers make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different and these differences may manifest themselves in farm performance and could be confounded with differences due purely to adoption. This situation, called self-selection, may bias the statistical results unless corrected (Fernandez-Cornejo et al. 2002).

To correct for self-selection bias, we follow Maddala (1983) and Greene (1995) and obtain consistent estimates of the parameters $\boldsymbol{\theta}$ and α by regarding self-selection and simultaneity (discussed earlier) as sources of endogenity. Because the dummy variable I cannot be treated as exogenous, instrumental variable techniques are used to purge the dependence of I. The predicted probability of adoption, obtained from the decision model, is used as an instrument for I in equation (21).

Unlike the traditional selectivity model, in which the effects are calculated (separately) using the subsamples of adopters and nonadopters, the impact model uses all the observations and is known as a "treatment effects model,"

used by Barnow et al. (1981). The treatment effects model consists of the regression $Y = \boldsymbol{\theta V}' + \alpha I + \varepsilon$ where the observed indicator variable I ($I = 1$ if $I^* > 0$ and $I = 0$ if $I^* \leq 0$), indicates the presence or absence of some treatment (adoption of herbicide-tolerant crops in this case) and the unobserved or latent variable I^* is given by $I^* = \boldsymbol{\delta} Z_a' + \nu$(Greene, 1995).

Total household income (NI^*), as represented in (17), has two components: household income from farming (*FARMHHI*) and off-farm household income (*TOTOFI*). Household income from farming includes farm business household income, operator's paid farm income, household members' paid farm income, etc. (see detailed definitions in appendix table 1). Off-farm household income includes off-farm business income, income from operating other farm businesses, off-farm wages and salaries, etc.

The components of vector $\boldsymbol{V}$ include farm location and typology, operator age, education and experience, number of children, price of soybeans, a measure of specialization on soybean production, a measure of the extent of livestock operations, farm size, and proxies for local labor market conditions.

The data are obtained from the nationwide Agricultural Resource Management Survey (ARMS) developed by USDA (USDA, ERS, 2003). The ARMS survey is designed to link data on the resources used in agricultural production to data on use of technologies, other management techniques, chemical use, yields, and farm financial/economic conditions for selected field crops. The ARMS is a multiframe, probability-based survey in which sample farms are randomly selected from groups of farms stratified by attributes such as economic size, type of production, and land use.

The 2000 data set (used for the HT soybean and Bt corn case study) includes 17 soybean (corn) producing States: Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Mississippi, Michigan, Minnesota, Missouri, Nebraska, North Carolina, Ohio, South Dakota, Tennessee, and Wisconsin. After selecting those farms that planted soybeans (corn) in 2000 and eliminating those observations with missing data, there were 2,258 observations available for the soybean analysis and 2513 observations for corn.

The 2001 corn data set (used for the yield monitor and conservation tillage case studies) includes observations of 17 corn-producing States. After eliminating observations with missing data, there were 1,763 observations available for analysis.

Because of the complexity of the survey design, a weighted least-squares technique is used to estimate the parameters using full-sample weights developed by the USDA's National Agricultural Statistics Service. Standard errors are estimated using a delete-a-group jackknife method (Kott, 1998; Kott and Stukel, 1997) where a group of observations is deleted in each replication. The sample is partitioned into r groups of observations (r = 15) and resampled, thus forming 15 replicates and deleting one group of observations in each replicate.

Appendix table 2 shows the parameter estimates α (equation 21) along with standard errors. These parameters may be interpreted as the derivatives of household income with respect to the probability of adoption and are used to obtain the elasticities shown in table 7.

Appendix table 1

Household (HH) income variable definitions

1. **Household income from farming (FARMHHI)** = Farm Business Income HH Share
   + Operator Paid on Farm
   + Household Members Paid on Farm
   + Net Income from Rented Land

Where:

Farm Business Income HH Share = Net Cash Farm Business Income
- Depreciation
- Gross Income from Rented Land
- Operator Paid Onfarm
- Income Due to Other Households

Net Cash Farm Income = Gross Cash Farm Income - Cash Operating Expenses

Gross Cash Farm Income = Crop and livestock income including CC loans + Other farm income (includes government payments, income from custom work and machine hire, income from livestock grazing, other farm-related income, income from farm land rented to others, fee income from crops removed under production contract, fee income from livestock removed under production contract).

Total Cash Operating Expenses (hired labor, contract labor, seed, fertilizer, chemicals, fuel, supplies, tractor and other equipment leasing, repairs, custom work, general business, real estate and property taxes, insurance, interest, purchased feed, purchased livestock).

2. **Off-Farm Household Income (TOTOFI)** = Off-farm business income
   + Income from operating other farm businesses
   + Off-farm wages and salaries
   + Interest and dividend income
   + Other off-farm income
   + Rental income

3. **Total Household Income (TOTHHI)** = Household Income from Farming (FARMHHI)
   + Off-Farm Household Income (TOTOFI)

Appendix table 2

Parameter estimates of probability of adoption term of the household income equation for technologies of varying managerial intensity

	Yield monitors			Bt corn			Conservation tillage			Herbicide-tolerant soybean		
	Estimate	std. err.	t-value	Estimate	std. err.	t-value	Estimate	std. err.	t-value	Estimate	std. err.	t-value
Onfarm household annual income	25.1	63.8	(0.39)	-13.9	10.9	(-1.29)	6.4	49.5	(0.13)	-30.4	29.8	(-1.02)
Off-farm household annual income	-124.9	35.3	(-3.54)	-36.7	36.2	(-1.07)	87.3	30.3	(2.88)	133.4	67.0	(1.99)
Total household annual income	-100.8	68.7	(-1.47)	-50.6	36.5	(-1.39)	93.9	51.3	(1.83)	104.1	59.0	(1.76)

Note. Standard errors calculated using the delete-a-group jackknife method.

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Preface

Not since the introduction of hybrid corn seed have we witnessed such a sweeping technological change in U.S. agriculture. Hundreds of thousands of farmers have adopted the first generation of genetically engineered (GE) crops since their commercialization in 1996. Although not all GE varieties that have been commercialized have succeeded, those targeted at improved pest control now cover over 80 percent of the acres planted to soybean, cotton, and corn—that is, almost half of U.S. cropland. Forecasts suggest an expansion in GE-crop plantings in many other countries.

GE crops originate in advances in molecular and cellular biology that enable scientists to introduce desirable traits from other species into crop plants or to alter crop plants' genomes internally. Those powerful scientific techniques have dramatically expanded the boundaries that have constrained traditional plant-breeding. A new technology adopted so widely and rapidly has substantial economic, social, and environmental impacts on farms and their operators. Inevitably, both advantages and risks or losses emerge from such massive changes. The National Research Council has conducted multiple studies of specific aspects of GE crops, such as regulatory-system adequacy and food safety. However, the assigned tasks restricted the scope of their reports. As pressure mounts to expand the use of GE crops for energy, food security, environmental improvement, and other purposes, the scope and intensity of impacts will grow. Now is an opportune time to take a comprehensive look at the track record of GE crops and to identify the opportunities and challenges looming on the horizon. The National Research Council therefore supported the Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability to investigate this topic.

Despite the rapid spread of GE crops in U.S. agriculture, the technology continues to stir controversy around scientific issues and ideological viewpoints. The committee focused on the scientific questions associated with the farm-level impacts of the adoption of genetic-engineering technology and refrained from analyzing ideological positions, either pro or con. The committee adopted an "evidentiary" standard of using peer-reviewed literature on which to form our conclusions and recommendations. It is my hope that the report will give readers a firm grasp of the state of evidence or lack thereof on the scientific issues.

True to its charge, the committee adopted a sustainability framework that required an evaluation of environmental, economic, and social impacts of GE crops. Those three dimensions constitute the essential pillars of sustainability science. The summary and opening and closing chapters bring together the three perspectives for a fuller view of the technology's impact.

Given the controversies, readers will want to know the committee's composition and how it conducted its work in arriving at conclusions and recommendations. The biographies in Appendix C show a group of highly accomplished natural and social scientists who possess a broad array of research experience and perspectives on GE crops. That diversity of disciplines

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and expertise proved beneficial in introducing checks and balances in evaluating information from many angles. The committee members divided into teams to work on the various sections of the report on the basis of the members' expertise. The drafts by each team were reviewed by the full committee to ensure that everyone had a chance to comment on and improve and approve each section. I was continually impressed with the members' dedication to a hard-nosed and impartial evaluation of the best science on GE crops. Equally important, they kept open minds in considering new evidence presented by their colleagues and external experts. The result was a model multidisciplinary research process in which each of us learned from the others and improved the report quality.

In closing, I want to express my deep appreciation to the committee members for their tireless work and good humor in completing such a challenging task while working full-time at their regular jobs. Their commitment and professionalism exemplify the best of public science. Each member made significant contributions to the final report. The committee also benefited from the testimony of several experts in the field and from the numerous comments of many conscientious external reviewers. Finally, the quality of the report would not have been attained without excellent support and substantive input by study director Kara Laney, the valuable assistance of Kamweti Mutu, the insightful counsel of Robin Schoen, and the editorial work of the National Research Council.

David E. Ervin, *Chair*
Committee on the Impact of
Biotechnology on Farm-Level
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This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council Report Review Committee. The purpose of the independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of the report:

David A. Andow, University of Minnesota, St. Paul
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by Drs. Alan G. McHughen, University of California, Riverside, and May R. Berenbaum, University of Illinois. Appointed by the National Research Council, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests with the authoring committee and the institution.

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Abbreviations and Acronyms

ACC	1-aminocycloprpane-1-carboxylic acid
ALS	acetolactate synthase
AMPA	aminomethylphosphonic acid
APHIS	Animal and Plant Health Inspection Service (U.S. Department of Agriculture)
BST	bovine somatotropin
Bt	*Bacillus thuringiensis*
Cry	Crystal-like (protein)
DNA	deoxyribonucleic acid
EPA	U.S. Environmental Protection Agency.
EPSPS	enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase
GE	genetically engineered
GMO	genetically modified organism
HPPD	hydroxyphenyl-pyruvate-dioxygenase
HR	herbicide-resistant
IAA	indoleacetic acid: a plant hormone (C10H9NO2) that stimulates growth
IPM	integrated pest management
IPR	intellectual property rights
IR	Insect-resistant
ISHRW	International Survey of Herbicide Resistant Weeds
MCL	maximum contaminant level
NOP	National Organic Program
NOSB	National Organic Standards Board

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PPO	protoporphyrinogen oxidase
PTO	U.S. Patent and Trademark Office
PVPA	Plant Variety Protection Act
R&D	Research and Development
USDA-ERS	U.S. Department of Agriculture, Economic Research Service
USDA-NASS	U.S. Department of Agriculture, National Agricultural Statistics Service
VR	virus-resistant
WHO	World Health Organization

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Summary

With the advent of genetic-engineering technology in agriculture, the science of crop improvement has evolved into a new realm. Advances in molecular and cellular biology now allow scientists to introduce desirable traits from other species into crop plants. The ability to transfer genes between species is a leap beyond crop improvement through previous plant-breeding techniques, whereby desired traits could be transferred only between related types of plants. The most commonly introduced genetically engineered (GE) traits allow plants either to produce their own insecticide, so that the yield lost to insect feeding is reduced, or to resist herbicides, so that herbicides can be used to kill a broad spectrum of weeds without harming crops. Those traits have been incorporated into most varieties of soybean, corn, and cotton grown in the United States.

Since their introduction in 1996, the use of (GE crops in the United States has grown rapidly and accounted for over 80 percent of soybean, corn, and cotton acreage in the United States in 2009. Several National Research Council reports have addressed the effects of GE crops on the environment and on human health.[1] However, the effects of agricultural biotechnology at the farm level—that is, from the point of view of the farmer—have received much less attention. To fill that information gap, the National Research Council initiated a study, supported by its own funds, of how GE crops have affected U.S. farmers—their incomes, agronomic practices, production decisions, environmental resources, and personal well-being. This report of the study's findings expands the perspectives from which genetic-engineering technology has been examined previously. It provides the first comprehensive assessment of the effects of GE-crop adoption on farm sustainability in the United States (Box S-1).

[1] *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects* (2004); *Environmental Effects of Transgenic Plants: The Scope and Adequacy of Regulation* (2002); *Ecological Monitoring of Genetically Modified Crops: A Workshop Summary* (2001); *Genetically Modified Pest-Protected Plants: Science and Regulation* (2000).

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BOX S-1
Statement of Task

An NRC committee will study the farm-level impacts of biotechnology, including the economics of adopting genetically engineered crops, changes in producer decision-making and agronomic practices, and farm sustainability.

The study will:

- review and analyze the published literature on the impact of GE crops on the productivity and economics of farms in the United States;
- examine evidence for changes in agronomic practices and inputs, such as pesticide and herbicide use and soil and water management regimes;
- evaluate producer decision-making with regard to the adoption of GE crops.

In a consensus report, the committee will present the findings of its study and identify future applications of plant and animal biotechnology that are likely to affect agricultural producers' decision-making in the future.

In interpreting its task, the committee chose to analyze the effects of GE crops on farm-level sustainability in terms of environmental, economic, and social effects. To capture the broad array of potential effects, the committee interpreted "farm level" as applying to both farmers who do not produce GE crops and those who do because genetic engineering is a technology of extensive scope, and its influences on farming practices have affected both types of farmers. Therefore, to the extent that peer-reviewed literature is available, the report draws conclusions about the environmental, economic, and social effects, both favorable and unfavorable, associated with the use of GE crops for all farmers in the United States over the last 14 years. The report encapsulates what is known about the effects of GE crops on farm sustainability and identifies where more research is needed. A full sustainability assessment of GE crops remains an ongoing task because of information gaps on certain environmental, economic, and social impacts.

Genetic-engineering technology continues to stir controversy around scientific issues and ideological viewpoints. This report addresses just the scientific questions and adopts an "evidentiary" standard of using peer-reviewed literature to form conclusions and recommendations. GE-trait developments may or may not turn out to be a cost-effective approach to addressing challenges confronting agriculture, but review of their impact and an exploration of what is possible are necessary to evaluate their relative efficacy. Therefore, the report details the challenges and opportunities for future GE crops and offers recommendations on how crop-management practices and future research and development efforts can help to realize the full potential offered by genetic engineering.

KEY FINDINGS

The order of findings in this summary reflects the structure of the report and does not connote any conclusions on the part of the committee regarding the relative strength or importance of the findings. In general, the committee finds that genetic-engineering technology has produced substantial net environmental and economic benefits to U.S. farmers compared

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with non-GE crops in conventional agriculture. However, the benefits have not been universal; some may decline over time, and the potential benefits and risks associated with the future development of the technology are likely to become more numerous as it is applied to a greater variety of crops. The social effects of agricultural biotechnology have largely been unexplored, in part because of an absence of support for research on them.

Environmental Effects

Generally, GE crops have had fewer adverse effects on the environment than non-GE crops produced conventionally. The use of pesticides with toxicity to nontarget organisms or with greater persistence in soil and waterways has typically been lower in GE fields than in non-GE, nonorganic fields. However, farmer practices may be reducing the utility of some GE traits as pest-management tools and increasing the likelihood of a return to more environmentally damaging practices.

Finding 1. When adopting GE herbicide-resistant (HR) crops, farmers mainly substituted the herbicide glyphosate for more toxic herbicides. However, the predominant reliance on glyphosate is now reducing the effectiveness of this weed-management tool.

Glyphosate kills most plants without substantial adverse effects on animals or on soil and water quality, unlike other classes of herbicides. It is also the herbicide to which most HR crops are resistant. After the commercialization of HR crops, farmers replaced many other herbicides with glyphosate applications after crops emerged from the soil (Figures S-1, S-2, and S-3). However, the increased reliance on glyphosate after the widespread adoption of HR crops is reducing its effectiveness in some situations. Glyphosate-resistant weeds have evolved where repeated applications of glyphosate have constituted the only weed-management tactic. Nine weed species in the United States have evolved resistance to glyphosate since the introduction of HR crops in 1996 compared with seven that have evolved resistance to glyphosate worldwide in areas not growing GE crops since the herbicide was commercialized in 1974. Furthermore, communities of weeds less susceptible to glyphosate are becoming established in fields planted with HR crops, particularly fields that are treated only with glyphosate.

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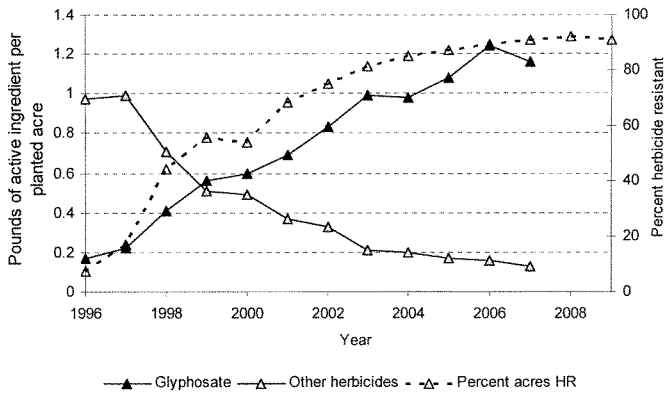


FIGURE S-1 Application of herbicide to soybean and percentage of acres of HR soybean.
NOTE: The strong correlation between the rising percentage of herbicide-resistant (HR) soybean acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

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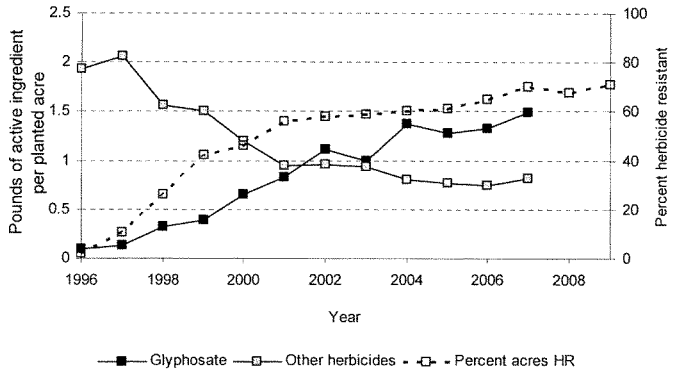


FIGURE S-2 Application of herbicide to cotton and percentage of acres of HR cotton.
NOTE: The strong correlation between the rising percentage of herbicide-resistant (HR) cotton acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

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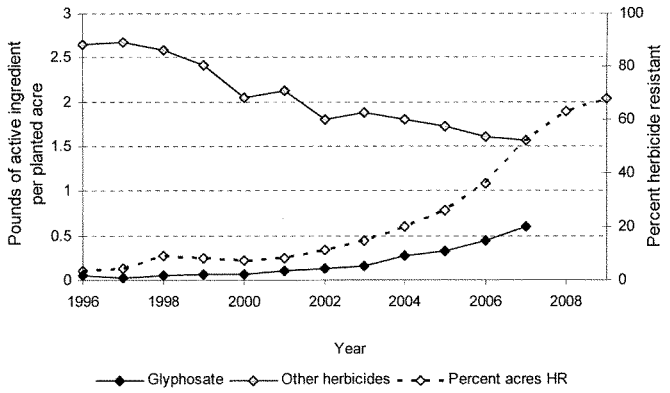


FIGURE S-3 Application of herbicide to corn and percentage of HR corn.
NOTE: The strong correlation between the rising percentage of herbicide-resistant (HR) corn acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

Finding 2. The adoption of HR crops complements conservation tillage practices, which reduce the adverse effects of tillage on soil and water quality.

Farmers have traditionally used tillage to control weeds in their fields, interrupting weed lifecycles before they can produce seeds for the following year. However, using tillage to help manage weeds reduces soil quality and increases soil loss from erosion. Tilled soil forms a crust, which reduces the ability of water to infiltrate the surface and leads to runoff that can pollute surface water with sediments and chemicals. Conservation tillage, which leaves at least 30 percent of the previous crop's residue on the field, improves soil quality and water infiltration and reduces erosion because more organic matter is left on the soil surface, thereby decreasing disruption of the soil. The adoption of HR crops allows some farmers to substitute glyphosate application for some tillage operations as a weed-management tactic and thereby benefits soil quality and probably improves water quality, although definitive research on the latter is lacking. However, empirical evidence points to a two-way causal relationship between the adoption of HR crops and conservation tillage. Farmers who use conservation tillage are more likely to adopt HR crop varieties than those who use conventional tillage, and those who adopt HR crop varieties are more likely to practice conservation tillage than those who use non-GE seeds.

Finding 3. Targeting specific plant insect pests with Bt corn and cotton has been successful, and the ability to target specific plant pests in corn and cotton continues to expand. Insecticide use has decreased with the adoption of insect-resistant (IR) crops. The

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emergence of insect resistance to Bt crops has been low so far and of little economic or agronomic consequence; two pest species have evolved resistance to Bt crops in the United States.

Bt toxins, which are produced by the soil-dwelling bacterium *Bacillus thuringiensis*, are lethal to the larvae of particular species of moths, butterflies, flies, and beetles and are effective only when an insect ingests the toxin. Therefore, crops engineered to produce Bt toxins that target specific pest taxa have had favorable environmental effects when replacing broad-spectrum insecticides that kill most insects (including beneficial insects, such as honey bees or natural enemies that prey on other insects), regardless of their status as plant pests. The amounts of insecticides applied per planted acre of Bt corn and cotton have inverse relationships with the adoption of these crops over time (Figures S-4 and S-5), though a causative relationship has not been established or refuted because other factors influence pesticide-use patterns.

Since their introduction in 1996, the use of IR crops has increased rapidly, and they continue to be effective. Data indicate that the abundance of refuges of non-Bt host plants and recessive inheritance of resistance are two key factors influencing the evolution of resistance. The refuge strategies mandated by the Environmental Protection Agency, and the promotion of such strategies by industry, likely contributed to increasing the use of refuges and to delaying the evolution of resistance to Bt in key pests. Nevertheless, some populations of two generalist pests have evolved resistance to Bt crops in the United States, although the agronomic and economic consequences appear to be minor. With the introduction of multiple Bt toxins in new hybrids or varieties, the probability of resistance to Bt crops is further reduced.

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FIGURE S-4 Pounds of insecticide applied per planted acre and percent acres of Bt corn, respectively.
NOTE: The strong correlation between the rising percentage of Bt corn acres planted over time and the decrease in insecticide pounds per planted acre suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

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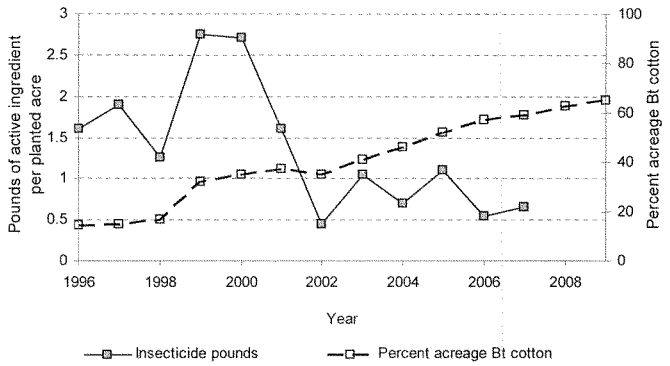


FIGURE S-5 Pounds of insecticide applied per planted acre and percent acres of Bt cotton, respectively.
NOTE: The strong correlation between the rising percentage of Bt cotton acres planted over time and the decrease in insecticide pounds per planted acre suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

Finding 4. For the three major GE crops, gene flow to wild or weedy relatives has not been a concern to date because compatible relatives of corn and soybean do not exist in the United States and are only local for cotton. For other GE crops, the situation varies according to species. However, gene flow to non-GE crops has been a concern for farmers whose markets depend on an absence of GE traits in their products. The potential risks presented by gene flow may increase as GE traits are introduced into more crops.

Gene flow between many GE crops and wild or weedy relatives is low because GE crops do not have wild or weedy relatives in the United States or because the spatial overlap between a crop and its relatives is not extensive. How that relationship changes will depend on what GE crops are commercialized, whether related species with which they are capable of interbreeding are present, and the consequences of such interbreeding on weed management. Gene flow of approved GE traits into non-GE varieties of the same crops (known as adventitious presence) remains a serious concern for farmers whose market access depends on adhering to strict non-GE presence standards. Resolving this issue will require the establishment of thresholds for the presence of GE material in non-GE crops, including organic crops, that do not impose excessive costs on growers and the marketing system.

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Economic Effects

The rapid adoption of GE crops since their commercialization indicates that the benefits to adopting farmers are substantial and generally outweigh additional technology fees for these seeds and other associated costs. The economic benefits and costs associated with GE crops extend beyond farmers who use the technology and will change with continuing adoption in the United States and abroad as new products emerge.

Finding 5. Farmers who have adopted GE crops have experienced lower costs of production and obtained higher yields in many cases because of more cost-effective weed control and reduced losses from insect pests. Many farmers have benefited economically from the adoption of Bt crops by using lower amounts of or less expensive insecticide applications, particularly where insect pest populations were high and difficult to treat before the advent of Bt crops.

The incomes of those who have adopted genetic-engineering technology have benefited from some combination of yield protection and lower costs of production. HR crops have not substantially increased yields, but their use has facilitated more cost-effective weed control, especially on farms where weeds resistant to glyphosate have not yet been identified. Lower yields were sometimes observed when HR crops were introduced, but the herbicide-resistant trait has since been incorporated into higher-yielding cultivars, and technological improvement in inserting the trait has also helped to eliminate the yield difference. In areas that suffer substantial damage from insects that are susceptible to the Bt toxins, IR crops have increased adopters' net incomes because of higher yields and reduced insecticide expenditures. Before the introduction of Bt crops, most farmers accepted yield losses to European corn borer rather than incur the expense and uncertainty of chemical control. Bt traits to address corn rootworm problems have lowered the use of soil-applied and seed-applied insecticides. In areas of high susceptible insect populations, Bt cotton has been found to protect yields with fewer applications of topical insecticides. More effective management of weeds and insects also means that farmers may not have to apply insecticides or till for weeds as often, and this translates into cost savings—lower expenditures for pesticides and less labor and fuel for equipment operations.

Finding 6. Adopters of GE crops experience increased worker safety and greater simplicity and flexibility in farm management, benefitting farmers even though the cost of GE seed is higher than non-GE seed. Newer varieties of GE crops with multiple GE traits appear to reduce production risk for adopters.

Farmers who purchase GE seed pay a technology fee—a means by which seed developers recover research and development costs and earn profits. GE seed is typically more expensive than conventional seed, and the net return in terms of higher yields and lower costs of production for a farmer considering adoption does not always offset the technology fee. However, studies have found that high rates of adoption of GE crops can be attributed in part to the value that farmers place on increased worker safety, perceived greater simplicity and flexibility in farm management (including more off-farm work opportunities), and lower production risk. Farmers and their employees not only face reduced exposure to the harsh chemicals found in some herbicides and insecticides used before the introduction of GE crops but have to spend less time in the field in applying the pesticides. Because glyphosate can be applied over a fairly wide

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timeframe, farmers who use HR crops have greater flexibility regarding when they treat weeds in their fields. Those benefits must be balanced with the risk that such flexibility in application timing may reduce crop-yield potential attributable to weed interference. Newer GE varieties that have multiple pest-control traits may result in more consistent pest management and thus less yield variability, a characteristic that has substantial value for risk-averse producers. The value of those benefits may provide additional incentives for adoption that counteract the extra cost of GE seed.

Finding 7. The effect GE crops have had on prices received by farmers for soybean, corn, and cotton is not completely understood.

Studies suggest that the adoption of GE crops that confer productivity increases ultimately puts downward pressure on the market prices of the crops. However, early adopters benefit from higher yields or lower production costs than nonadopters even with lower prices. The gains tend to dissipate as the number of adopters increases, holding technological progress constant. Thus, as the first adopters, U.S. farmers have generally benefited economically from the fact that GE crops were developed and commercialized in the United States before they were planted by farmers in other countries. The extent to which GE-crop adoption in developing countries will influence productivity and prices, and therefore U.S. farm incomes, is not completely understood. There is a paucity of studies of the economic effects of genetic-engineering technology in recent years even though adoption has increased globally.

Finding 8. To the extent that economic effects of GE-crop plantings on non-GE producers are understood, the results are mixed. By and large, these effects have not received adequate research.

Decisions made by adopters of GE crops can affect the input prices and options for both farmers who use feed and food products made with GE ingredients and farmers who have chosen not to grow GE seed or do not have the option available. The latter effects on those not using genetic-engineering technology have not been studied extensively. Livestock producers constitute a large percentage of corn and soybean buyers and therefore are major beneficiaries of any downward pressure on crop price due to the adoption of GE crops. Feed costs are nearly half the variable costs for livestock producers, so even moderate price fluctuations can affect their net incomes substantially. Livestock producers also benefit from increased feed safety due to reduced levels of mycotoxins in the grain. However, no quantitative estimation of savings to livestock operators due to the adoption of GE crops and the resulting effect on the profitability of livestock operations has been conducted. Similarly, a number of other economic effects predicted by economic theory have not been documented.

Favorable and unfavorable externalities are not limited to the cost and availability of inputs. To the extent that genetic-engineering technology successfully reduces pest pressure on a field and regionally, farmers of fields in the agricultural landscape planted with non-GE crops may benefit via lower pest-control costs associated with reductions in pest populations. However, nonadopters of genetic-engineering technology also could suffer from the development of weeds and insects that have acquired pesticide resistance in fields within the region planted to GE crops. When that happens, farmers might have to resort to managing the resistant pests with additional, potentially more toxic or more expensive forms of control, even though their practices may not have led to the evolution of resistance.

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Inadvertent gene flow from GE to non-GE varieties of crops can increase production costs. Gene flow occurs through cross-pollination between GE and non-GE plants from different fields, co-mingling of GE seed with non-GE seed, and germination of seeds left behind (volunteers) after the production year. Similarly, if GE traits cross into weedy relatives, weed-control expenses will be higher for all fields on to which the weeds spread, whether a farmer grows GE crops or not. In addition, gene flow of GE traits into organic crops could jeopardize crop value by rendering outputs unsuitable for high-value foreign or other markets that limit or do not permit GE material in food products; the extent of that effect has not been documented during the last 5 years. On the other hand, the segregation of GE traits from organic production may have benefited organic producers by creating a market in which they can receive a premium for non-GE products.

Social Effects

The use of GE crops, like the adoption of other technologies at the farm level, is a dynamic process that both affects and is affected by the social networks that farmers have with each other, with other actors in the commodity chain, and with the broader community in which farm households reside. However, the social effects of GE-crop adoption have been largely overlooked.

Finding 9. Research on the dissemination of earlier technological development in agriculture suggests that favorable and unfavorable social impacts exist from the dissemination of genetic-engineering technology. However, these impacts have not been identified or analyzed.

Because GE crops have been widely adopted rapidly, it is reasonable to hypothesize that there have been social effects on adopters, nonadopters, and farmers who use GE products, such as livestock producers. For example, based on earlier research on the introduction of new technologies in agriculture, it is possible that certain categories of farmers (such as those with less access to credit, those with fewer social connections to university and private-sector researchers, or those who grow crops for smaller markets) might be less able to access or benefit from GE crops. The introduction of genetic-engineering technology in agriculture could also affect labor dynamics, farm structure, community viability, and farmers' relationships with each other and with information and input suppliers. However, the extent of the social effects of the dissemination of GE crops is unknown because little research has been conducted.

Finding 10: The proprietary terms under which private-sector firms supply GE seeds to the market has not adversely affected the economic welfare of farmers who adopt GE crops. Nevertheless, ongoing research is needed to investigate how market structure may evolve and affect access to non-GE or single-trait seed. Furthermore, there has been little research on how increasing market concentration of seed suppliers affects overall yield benefits, crop genetic diversity, seed prices, and farmers' planting decisions and options.

During the 20th century, the U.S. seed industry evolved from small, family-owned businesses that multiplied seeds developed by university scientists to a market dominated by a handful of large, diversified companies. Universities still contribute to seed development, but seed

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companies have invested considerably in the research, development, and commercialization of patent-protected GE traits for large seed markets. Thus, corn, soybean, and cotton have received the bulk of private research attention in the last few decades. Large seed companies have not commercialized GE traits in many other crops because their market size has been insufficient to cover necessary research and development costs or because of concerns related to consumer acceptance and gene flow. Public research institutions continue to enhance the genetics of other crops, but full access to state-of-the-art technology (like genetic engineering) that may be beneficial to crops in smaller markets is often not available to public researchers because of patent protections.

Studies conducted in the first few years after the introduction of GE crops found no adverse effects on farmers' economic welfare from the consolidation of market power in the seed industry. However, the current developmental trajectory of GE-seed technology is causing some farmers to express concern that access to seeds without GE traits or to seeds that have only the specific GE traits that are of particular interest to farmers will become increasingly limited. Additional concerns are being raised about the lack of farmer input into and knowledge about which seed traits are being developed. Although the committee was not able to find published peer-reviewed material that documented the degree of U.S. farmers' access to non-GE seed and the quality of the seed, testimony provided to the committee suggests that access to non-GE or nonstacked seed may be restricted for some farmers or that available non-GE or nonstacked seed may be available in older cultivars that do not have the same yield characteristics as newer GE cultivars.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 1. Weed problems in fields of HR crops will become more common as weeds evolve resistance to glyphosate or weed communities less susceptible to glyphosate become established in areas treated exclusively with that herbicide. Though problems of evolved resistance and weed shifts are not unique to HR crops, their occurrence, which is documented, diminishes the effectiveness of a weed-control practice that has minimal environmental impacts. Weed resistance to glyphosate may cause farmers to return to tillage as a weed-management tool and to the use of potentially more toxic herbicides.

A number of new genetically engineered HR cultivars are currently under development and may provide growers with other weed management options when fully commercialized. However, the sustainability of those new GE cultivars will also be a function of how the traits are managed. If they are managed in the same fashion as the current genetically engineered HR cultivars, the same problems of evolved herbicide resistance and weed shifts may occur. Therefore, farmers of HR crops should incorporate more diverse management practices, such as herbicide rotation, herbicide application sequences, and tank-mixes of more than one herbicide; herbicides with different modes of action, methods of application, and persistence; cultural and mechanical control practices; and equipment-cleaning and harvesting practices that minimize the dispersal of HR weeds.

Recommendation 1. Federal and state government agencies, private-sector technology developers, universities, farmer organizations, and other relevant stakeholders should collaborate to document emerging weed-resistance problems and to develop cost-effective

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resistance-management programs and practices that preserve effective weed control in HR crops.

Conclusion 2. Given that agriculture is the largest source of surface water pollution, improvements in water quality resulting from the complementary nature of herbicide-resistance technology and conservation tillage may represent the largest single environmental benefit of GE crops. However, the infrastructure to track and analyze these effects is not in place.

Recommendation 2. The U.S. Geological Survey and companion federal and state environmental agencies should receive the financial resources necessary to document the water quality effects related to the adoption of GE crops.

Conclusion 3. The environmental, economic, and social effects on adopters and nonadopters of GE crops has changed over time, particularly because of changes in pest responses to GE crops, the consolidation of the seed industry, and the incorporation of GE traits into most varieties of corn, soybean, and cotton. However, empirical research into the environmental and economic effects of changing market conditions and farmer practices have not kept pace. Furthermore, little work has been conducted regarding the effects on livestock producers and nonadopters and on the social impacts of GE crops. Issues in need of further investigation include the costs and benefits of shifts in pest management for non-GE producers due to the adoption of GE crops, the value of market opportunities afforded to organic farmers by defining their products as non-GE crops, the economic impacts of GE-crop adoption on livestock producers, and the costs to farmers, marketers, and processors of the presence of approved or unapproved GE traits and crops in products intended for restricted markets. As more GE traits are developed and inserted into existing GE crops or into other crops, understanding the impacts on all farmers will become even more important to ensuring that genetic-engineering technology is used in a way that facilitates environment, economic, and social sustainability in U.S. agriculture.

Recommendation 3. Public and private research institutions should allocate sufficient resources to monitor and assess the substantial environmental, economic, and social effects of current and emerging agricultural biotechnology on U.S. farms so that technology developers, policymakers, and farmers can make decisions that ensure genetic engineering is a technology that contributes to sustainable agriculture.

Conclusion 4. Commercialized GE traits are targeted at pest control, and when used properly, they have been effective at reducing pest problems with economic and environmental benefits to farmers. However, genetic engineering could be used in more crops, in novel ways beyond herbicide and insecticide resistance, and for a greater diversity of purposes. With proper management, genetic-engineering technology could help address food insecurity by reducing yield losses through its introduction into other crops and with the development of other yield protection traits like drought tolerance. Crop biotechnology could also address "public goods" issues that will be undersupplied by the market acting alone. Some firms are working on GE traits that address public goods issues. However, industry has insufficient incentive to invest enough in research and development for those purposes when firms cannot collect revenue from innovations that generate net benefits

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beyond the farm. Therefore, the development of these traits will require greater collaboration between the public and private sectors because the benefits extend beyond farmers to the society in general. The implementation of a targeted and tailored regulatory approach to GE-trait development and commercialization that meets human and environmental safety standards while minimizing unnecessary expenses will aid this agenda (Ervin and Welsh, 2006).

Recommendation 4. Public and private research institutions should be eligible for government support to develop GE crops that can deliver valuable public goods but have insufficient market potential to justify private investment. Intellectual property patented in the course of developing major crops should continue to be made available for such public goods purposes to the extent possible. Furthermore, support should be focused on expanding the purview of genetic-engineering technology in both the private and public sectors to address public goods issues. Examples of GE-crop developments that could deliver such public goods include but are not limited to

- *plants that reduce pollution of off-farm waterways through improved use of nitrogen and phosphorus fertilizers,*
- *plants that fix their own nitrogen and reduce pollution caused by fertilizer application,*
- *plants that improve feedstocks for renewable energy,*
- *plants with reduced water requirements that slow the depletion of regional water resources,*
- *plants with improved nutritional quality that deliver health benefits, and*
- *plants resilient to changing climate conditions.*

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1

Introduction

Historians often link the advent of human civilizations with the transition of human societies from food collection primarily through hunting and gathering to food production in established agricultural systems. In a pattern of parallel development, early agricultural systems began emerging in separate regions during the Neolithic period some 10,000 years ago (Mazoyer and Roudart, 2006). Crop-improvement practices based on identification and selection of the best plant varieties appear to date back to the early days of agriculture itself. Similarly, early pastoralists engaged in selective animal breeding. That those practices were recognized as important in the development of ancient human civilizations is apparent in the preservation of instructions on plant breeding in writing, such as in the works of Virgil and Theopastus (Vavilov, 1951). In the broadest sense, the term *biotechnology* can encompass a wide array of procedures used to modify organisms according to human needs. It can be argued that early agriculturalists engaged in a simple form of biotechnology (Kloppenburg, 2004) in developing the intention and the techniques to improve plant varieties and animal species.

Although the process of plant and animal improvement has been continuous throughout the history of agriculture, some historical periods can be identified as singularly transformative. For example, a major agricultural revolution took place in Europe from the 16th to the 19th century. It was characterized in part by the extensive use of plants and animals that had been imported from the Americas (Crosby, 2003) and by animal-drawn cultivation and the use of fertilizers, the latter permitting cereal and feed-grain cultivation without fallowing (Mazoyer and Roudart, 2006). That revolution led to important increases in the food supply and thus ultimately permitted increased population growth.

Another important change in agriculture resulted from the application of an increasingly scientific approach to plant breeding, which developed from the recognition of the cell as the primary unit of all living organisms in the 1830s (Vasil, 2008) and the work of Mendel (Kloppenburg, 2004). With the rediscovery of Mendel's principles of genetics in the early 1900s, progress in plant and animal breeding was accelerated. The continuous growth in crop yields and agricultural productivity during the 20th century owes much to those biological discoveries and to a series of mechanical and chemical innovations driven by agricultural research and development.

One of the more significant innovations in plant breeding during the 20th century was the development of hybrid crops, particularly corn, in the United States. Hybrid corn varieties, which are developed from crossing different inbred lines, out-yield pure inbred lines, though the seeds

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produced by hybrid varieties yield poorly. When corn hybrids were first developed, they had no discernible yield advantage over the existing open-pollinated corn varieties of the time (Lewontin, 1990). However, seed companies were motivated to develop high-yielding hybrid varieties; saving and planting the seeds of hybrid corn did not produce equal yields, so seed companies had a financial incentive to invest in these varieties. The research and development efforts devoted to hybrid corn produced tremendous yield improvements over the last 70 years. It is unclear if the same amount of investment could have resulted in similar yield increases for open-pollinated varieties; regardless, because of their limited potential for return on financial investment, efforts to develop high-yielding open-pollinated varieties were not made. Modern hybrids, which have been bred to allocate more of their energy to producing grain rather than stover (leaves and stalks), also demonstrate an ability to maintain high grain production in densely planted fields (Liu and Tollenaar, 2009), and they can exhibit increased tolerance to environmental stresses (such as drought, cold, and light availability).

Plant breeders in the 20th century also identified varieties of wheat and rice with shorter stalks and larger seed heads. They were crossed with relatives to create semidwarf wheat and rice varieties, which produced greater yields in part because they responded well to applications of nitrogen and did not lodge despite having heavier seed heads. The development of semidwarf wheat and rice spurred the Green Revolution of the 1960s and 1970s in developing countries (Conway, 1998). Such improvements in plant breeding increased global crop yields in rice and wheat substantially in countries with suitable growing conditions and markets.

Recent developments in scientific plant breeding have resulted from discoveries in molecular and cellular biology in the second half of the 20th century that laid the foundation for the development of genetically engineered plants. In 1973, the American biochemists Stanley Cohen and Herbert Boyer were among the first scientists to transfer a gene between unrelated organisms successfully. They cut DNA from an organism into fragments, rejoined a subset of those fragments, and added the rejoined subset to bacteria to reproduce. The replicated DNA fragments were then spliced into the genome of a cell from a different species, and this created a transgenic organism, that is, an organism with genes from more than one species. Before the advent of genetic engineering, plant tissue-culture technology expanded the array of available genetic material beyond what was possible with traditional plant breeding by manipulating the fertilization and embryos of crosses between more distantly related species (Brown and Thorpe, 1995). DNA-recombination techniques opened the possibility of augmenting plant genomes with desirable traits from other species and thus took the science of plant breeding to a stage in which improvement is constrained not by the limits of genetic traits within a particular species but rather by the limits of discovery of genes and their transfer from one species to another to confer desired characteristics on a particular crop.

COMMITTEE CHARGE AND APPROACH

The committee's study was the first comprehensive assessment of the impacts of the use of genetically engineered (GE) crops on farm sustainability in the United States. The most up-to-date, available scientific evidence from all regions was used to assemble a national picture that would reflect important variations among regions. Box 1-1 presents the formal statement of task assigned to the committee.

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BOX 1-1
Statement of Task Summary

An NRC committee will study the farm-level impacts of biotechnology, including the economics of adopting genetically engineered crops, changes in producer decision-making and agronomic practices, and farm sustainability.
The study will:

- review and analyze the published literature on the impact of GE crops on the productivity and economics of farms in the United States;
- examine evidence for changes in agronomic practices and inputs, such as pesticide and herbicide use and soil and water management regimes;
- evaluate producer decision-making with regard to the adoption of GE crops.

In a consensus report, the committee will present the findings of its study and identify future applications of plant and animal biotechnology that are likely to affect agricultural producers' decision-making in the future.

In conducting its task, the committee interpreted the term *sustainability* to apply to the environmental, economic, and social impacts of genetic-engineering technology at the farm level. That interpretation is in line with the federal government's definition of *sustainable agriculture*, which is "an integrated system of plant and animal production practices having a site-specific application that will over the long-term:

1. Satisfy human food and fiber needs.
2. Enhance environmental quality and the natural resource base upon which the agriculture economy depends.
3. Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
4. Sustain the economic viability of farm operations.
5. Enhance the quality of life for farmers and society as a whole." (U.S.C. Title 7 § 3103, 2009)

This definition conceives of sustainable farming systems that address salient environmental, economic, and social aspects and their interrelationships.

The report explores how GE crops contribute to achieving several of the conditions enumerated above. Farmers must continually adapt in response to environmental, economic, and social conditions by learning and adopting new practices. Adopting GE crops is one option some farmers make in adapting to changing conditions.

Though the three aspects of sustainability often interact with one another, the report organizes each in a separate chapter to facilitate access to the information. The chapter on production economics follows the environmental chapter because many of the economic gains and losses that farmers experience with GE crops result from changes occurring within the farm environment from GE-crop adoption. The chapter on social effects is brief because of a lack of published literature on the subject. Nevertheless, the committee deemed this aspect important to include for two reasons. First, social impacts are widely considered to be a necessary element in the definition of sustainability as noted earlier. Second, with the sizable shift in cropping

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practices and systems to genetic-engineering technology (and the prospect of more GE crops to come), the marked expansion of private-sector control of intellectual property related to seeds, and a growing concentration of private-sector seed companies, it is the committee's estimation that GE crops have had and will continue to have social repercussions at the farm and community levels. The committee agreed that the report should draw attention to need for research in this area. In this vein, the report highlights issues on which insufficient information is available for drawing firm conclusions. The final chapter summarizes the main findings of the assessment and discusses the potential for future GE crops to address emergent food, energy, and environmental challenges.

The committee interpreted the statement of task to be retrospective in nature, examining the sustainability effects of GE crops on U.S. farms since their commercialization. For that reason the committee focused in large part on the experiences of soybean, corn, and cotton producers because GE varieties of those crops have been widely adopted by farmers, those crops are planted on almost half of U.S. cropland, and most research on genetic-engineering technology in agriculture has targeted those three crops. However, the committee recognized that most farmers have been affected by the widespread adoption of GE crops, even if they have chosen not to adopt them or have not had the option to adopt them. The report examined the effects of genetic-engineering technology on those producers as well. Because the study was retrospective and focused on the experience of U.S. farmers, the adoption of GE crops in other countries entered into the analysis only if U.S. farmers have experienced effects of such adoption, and the committee restricted its speculations on the future applications and implications of genetic-engineering technology to the final chapter.

The National Research Council supported the study to expand its contributions to the understanding of agricultural biotechnology. Committee members were chosen because of their academic research and experience on the topic. Experts were selected from the fields of weed science, agricultural economics, ecology, rural sociology, environmental economics, entomology, and crop science. To prepare its report, the committee reviewed previous studies and scientific literature on farmers' adoption of genetic-engineering technology, the impacts of such technology on non-GE farmers, and environmental impacts of GE crops. It also examined historical and current statistical data on the adoption of GE crops in the United States. The committee acknowledges that GE crops in U.S. agriculture continue to stir controversy around scientific issues and ideological viewpoints. With this in mind, the committee kept its focus on scientific questions and adopted an evidentiary standard of using peer-reviewed literature upon which to base its conclusions and recommendations. It refrained from analyzing ideological positions, either in support of or against the technology, in order to remain as impartial as possible.

STUDY FRAMEWORK

An analysis of the farm-level sustainability impacts of GE crops requires a framework that integrates all salient factors that motivate their use. We use the principal theories applied to agricultural technology adoption to construct a framework that identifies the qualitative factors that affect U.S. farmers' decisions to use genetic-engineering technology. With an understanding of the adoption and use processes, we then outline an evaluation framework that spans environmental, economic, and social dimensions as noted above.

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Two main theories help in building a framework for analyzing a farmer's decision to adopt a particular GE crop. First, "diffusion" theory seeks to explain people's propensities to adopt innovations as communicated through particular channels and within particular social systems (Rogers, 2003). Second, "threshold" theory delves deeper into the economic influences on farmer decisions by considering the heterogeneity in farm sizes, in agronomic conditions (climate, soil, water availability, and pest pressure), in forms of human capital that influence learning by doing and using, and in operator values (Feder et al., 1985; Foster and Rosenzweig, 1995; Fischer et al., 1996; Marra et al., 2001; Sunding and Zilberman, 2001). Incorporating those factors allows a better qualitative understanding of the dynamics of the spread of the technologies across the landscape and of their impacts. Together, the diffusion and threshold theories point to five sets of factors that exert influences on a farmer's decision to use genetic-engineering technology:

1. Productivity (yield) effects.
2. Market structure and price effects.
3. Production input effects.
4. Human capital and personal values.
5. Information and social networks.

Productivity Effects

Genetic-engineering technology can directly and indirectly affect crop yields, either positively or negatively, as explained in Chapter 3 in more detail. The direct route stems from the effect on a cultivar after the insertion of one or more traits through genetic engineering. The indirect effect is related to the ability of a GE crop to decrease pest damage (Lichtenberg and Zilberman, 1986a). Just as natural-resource conditions, including pest pressures, vary among fields, farms, and regions, so will the indirect effects on yield and the rate of adoption of GE crops. The technologies tend to be adopted in locations whose agrophysical conditions—such as land quality, climate, and vulnerability to pests—lead to productivity gains (Marra et al., 2003; Zilberman et al., 2003). In addition to effects on quantity, genetic engineering may affect the quality of a crop, which influences its value.

Market-Structure and Price Effects

Farmers who are deciding whether to grow GE crops must consider their access to domestic and foreign markets. Differential access may stem from country regulations on the entry of GE crops into their markets or from lack of market infrastructure (for example, segmentation of GE and non-GE product chains). Farmers who choose to grow GE crops may experience higher or lower prices than if they grow non-GE crops. For example, if enough farmers adopt a GE crop and yields increase substantially because of direct or indirect effects, crop prices may be forced down by increased supplies, other characteristics remaining the same. Consumers of GE crops may benefit from the lower prices, though some consumers may be willing to pay more for non-GE crops for personal reasons, and this may create a premium for non-GE crops. Under other circumstances, global demand increases may absorb most or all of the increase in supply, in which case prices would not decline (see Chapter 3).

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Market access and price effects alter farmers' revenues and profitability and thus their disposition to adopt GE crops. The organizational hierarchy of the commodity chain and the nature of farm policies can create structural conditions that act as impediments to or inducers of adoption of a technology (Mouzelis, 1976; Bonanno, 1991; Friedland, 2002; Kloppenburg, 2004). For example, the development of crops with more than one GE trait may create a structural condition for some farmers whereby they may have to pay for traits that they do not need in order to gain access to the traits that they desire (see Chapter 4).

Production-Input Effects

The adoption and use of GE crops can precipitate changes in the types, amounts, and timing of pesticide use and in the types, frequency, and timing of tillage operations; both can affect machinery requirements. Those changes are referred to as substitution effects; an example is the replacement of some pesticides with a GE crop (Lichtenberg and Zilberman, 1986b). A shift in labor requirements is another potentially important production-input effect (Fernandez-Cornejo and Just, 2007). The availability and quality of GE and non-GE seeds may affect a farmer's decision to use either. For example, the commercial success of the application of GE soybean and corn in the 1990s was accompanied by increased consolidation and vertical integration in the seed industry (Fernandez-Cornejo, 2004). Indeed, by 1997, two firms captured 56 percent of the U.S. corn-seed market, and this share has increased even more in recent years (see "Interaction of the Structure of the Seed Industry and Farmer Decisions" in Chapter 4) (Boyd, 2003). The changes in genetic-engineering technology and seed-industry structure may help to explain anecdotal statements about the reduced availability of some non-GE seed varieties in recent years (Hill, personal communication). However, the committee is not aware of any published research confirming the link between seed-industry structure and seed availability.

Human Capital and Personal Values

Every major study of agricultural-technology adoption has found that at least some aspects of human capital play a role in the process. Frequently, the more education or experience a farmer has, the more likely he or she is to adopt a new technology. Educational achievement and years of experience in farming are thought to be proxies for a potential adopter's ability to learn quickly how to adapt the new technology to the farm operation and to use it to its greatest advantage. As noted above, the process of learning and adaptation is critical to the development of more sustainable farming systems. Farmers also may hold personal values that affect their decisions to use GE crops beyond the financial effects that may flow from productivity, value, and production input. A person's values define preferences and have been shown to influence decisions on genetic-engineering development and applications (Piggott and Marra, 2008; Buccola et al., 2009). Examples of personal values include aversion to general and specific risks, preference for environmental stewardship, and ideological positions about agricultural systems. An example of the influence of risk aversion is some farmers' preference for GE crops if they reduce the variability of yields because they improve control of pests. Such risk reduction can motivate adoption of GE varieties by risk-averse farmers and may also lead to an increase in use of complementary practices, such as no-till planting (Alston et al., 2002; Piggott and Marra, 2007).

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Information and Social Networks

Decisions of whether to adopt GE crops hinge on the quantity and quality of farmers' information about the characteristics and performance of the technologies. Information from formal sources, such as the agricultural media, on GE traits' technical aspects, economic implications, and prospects can shape farmers' views. Informal sources probably also speed or slow the adoption of GE crops (Wolf et al., 2001; Just et al., 2002). Social networks can have favorable or unfavorable effects not only on the adoption of technologies but also on the sharing of knowledge about GE and non-GE crops and on the development of new technologies and management strategies (Arce and Marsden, 1993; Busch and Juska, 1997; Hubbell et al., 2000). They can also mitigate potentially negative social impacts of GE-crop adoption. Recognition of the importance of social networks has been enhanced by studies of the processes associated with the use of alternative agricultural practices (Storstad and Bjørkhaug, 2003; Morgan et al., 2006). Insights derived from the study of social networks also may have great relevance to the development and dispersion of genetic-engineering technology.

Figure 1-1 portrays the influences of the different factors on GE-crop adoption decisions and the resultant impacts on environmental, economic, and social conditions. This conceptual model shows that factors under the control of the farmer, such as human capital, and outside their control, such as market prices, come together to influence the GE-crop adoption decision process, depicted by the central box in the figure. It also shows how the factors, up to this point presented as having distinct effects, may influence each other. Examples of potential interactions include the effects of information and social networks on personal values and production inputs and the effect of production-input substitution on productivity. Other impacts of decisions related to GE crops (for example, the environmental effect of pest population changes) may feed back to some influencing factors, such as production inputs. As discussed later in this chapter, empirical studies have found that factors in each of the categories have influenced GE-crop adoption patterns. However, it is not possible to rank the magnitude of influences in a general sense. Rather, we expect that the different factors will vary in influence across types of farms, geographic regions, and specific crop applications. For example, if a certain pest infestation is severe in a region, then the productivity gains from adopting a GE crop may far outweigh the influence of personal values of the adopter. In another case where pest pressures are moderate compared to other regions, functioning information and social networks may influence the speed and rate of adoption of genetic-engineering technology.

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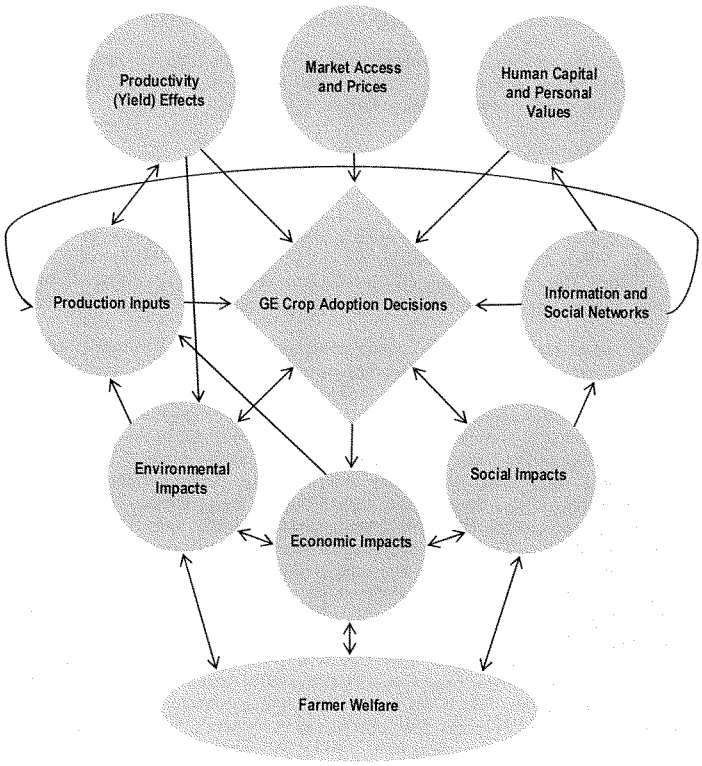


FIGURE 1-1 Genetically engineered crop adoption and impact framework.

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GENETICALLY ENGINEERED TRAITS IN CROPS

For agricultural crops, the first generation of genetic engineering has targeted traits that increase the efficacy of pest control. Since the introduction of GE crops, new seeds have provided pest control in one or more of three forms:

- Herbicide resistance.
- Insect resistance.
- Virus resistance.

The terms *resistance* and *tolerance* are often used interchangeably in the literature. *Tolerance* implies that a crop is affected by a pesticide but has a means to naturally survive the potential damage sustained. This report uses the more precise term *resistance* because altered genes either allow a plant to generate its own insecticide or prevent herbicides from damaging the plant (Roy, 2004).

GE herbicide-resistant (HR) crops contain transgenes that enable survival of exposure to particular herbicides. In the United States, crops are available with GE resistance to glufosinate and glyphosate, but most HR crops grown in the United States are resistant only to glyphosate, a nonselective chemical that has a low impact on the environment. Glyphosate inhibits the enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS), which is part of the shikimate pathway in plants. The shikimate pathway helps produce aromatic amino acids; it is speculated that glyphosate kills a plant either by reducing aromatic amino acid production and adversely affecting protein synthesis or by increasing carbon flow to the glyphosate-inhibited shikimate pathway, causing carbon shortages in other pathways (Duke and Powles, 2008). The susceptibility of EPSPS to the chemical and the relative ease with which it is taken up by a plant make glyphosate an extremely effective herbicide. It presents a low threat of toxicity to animals in general because they do not have a shikimate pathway for protein synthesis (Cerdeira and Duke, 2006). Glyphosate also has low soil and water contamination potential because it binds readily to soil particles and has a relatively short half-life in soil (Duke and Powles, 2008).

Insect-resistant (IR) plants grown in the United States have genetic material from the soil-dwelling bacterium *Bacillus thuringiensis* (Bt) incorporated into their genome that provides protection against particular insects. Bt produces a family of endotoxins, some of which are lethal to particular species of moths, flies, and beetles. An insect's digestive tract activates the ingested toxin, which binds to receptors in the midgut; this leads to the formation of pores, cell lysis, and death. Individual Bt toxins have a narrow taxonomic range of action because their binding to midgut receptors is specific; the toxicity of Bt crops to vertebrates and many nontarget arthropods and other invertebrates in U.S. agricultural ecosystems is effectively absent. The first Bt crops that were introduced produced only one kind of Bt toxin. More recent varieties produce two or more Bt toxins; this enhances control of some key pests, allows control of a wider array of insects, and can contribute to delaying the evolution of resistance in target pests while reducing refuge size.

Gene sequences of pathogenic viruses have been inserted into crops to confer protection against related viruses—to make them virus-resistant (VR). Most transgenic VR plants resist viruses through gene silencing, which occurs when transcription of a transgene induces degradation of the genome of an invading virus. Potential unwanted environmental effects of VR crops include exchanges between viral pathogens and transgene products that could increase the virulence of viral pathogens, food allergenicity, and transgene movement through pollen, which

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can create VR weeds. Adverse environmental effects of commercialized VR plants have not been found (Fuchs and Gonsalves, 2008).

HR and IR crops, having been the principal targets of most efforts to develop GE crop varieties, account for the bulk of acres planted in GE crops in the United States. Consequently, this report focuses on farmers' experiences with these types of GE crops. HR varieties of soybean, corn, cotton, canola, and sugar beets and IR varieties of corn and cotton were grown commercially in 2009. Herbicide resistance and insecticide resistance are not mutually exclusive; a number of crop varieties that contain both types of resistance have been developed. GE corn and cotton may also express more than one type of Bt trait. Seeds with multiple GE characteristics are referred to as "stacked cultivars".

Herbicide resistance and insect resistance were commercialized because of the relative simplicity in gene transfer and the utility for farmers. The expression of those traits requires manipulation of the genetic code at only one site, a relatively straightforward process compared with such traits as drought tolerance, which involve the action of many genes. Furthermore, because corn, soybean, and cotton production accounts for the bulk of pesticide expenditures in the United States (Figure 1-2), herbicide resistance and insect resistance provided important market opportunities. Those GE crops fit easily into the traditional pest-management approach of mainstream U.S. agriculture: reliance on the continual emergence of technological advances to address pest problems, particularly after development of resistance to an earlier innovation. Therefore, the familiarity of the chemicals involved, the size of the market for the seeds of and pesticides for GE crops, and the ease of manipulation of the genes for the traits contributed to HR and IR seeds' being the first GE products to emerge in large-scale agriculture.

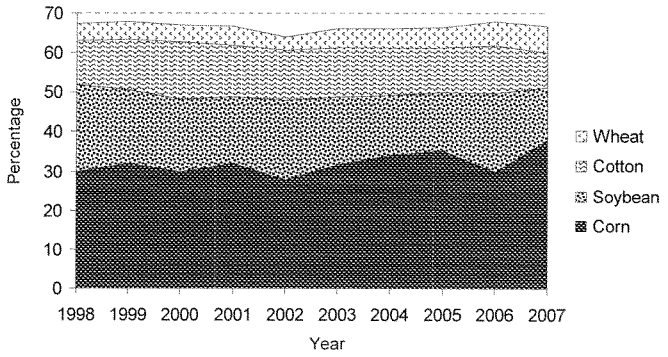


FIGURE 1-2 Share of major crops in total pesticide expenditures, 1998–2007.
NOTE: Includes expenditures in herbicides, insecticides, and fungicides. Genetically engineered trait technology fees are not included.
SOURCE: Fernandez-Cornejo et al., 2009.

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ADOPTION AND DISTRIBUTION OF GENETICALLY ENGINEERED CROPS

Crops with GE traits aimed primarily at pest control have been widely adopted in the United States by farmers of corn, cotton, soybean, canola, and sugar beet and have caused substantial changes in farm-management practices and inputs, such as changes in pesticide use. In 2008, almost half of U.S. cropland was planted with GE seed, even though the technology had been available to farmers only since the middle 1990s and only a few crops have experienced commercial success (USDA-NASS, 2009b). U.S. farmers planted 158 million acres of GE crops in 2009—nearly half of all the GE-crop acres in the world (James, 2009). Rates of adoption have been influenced by the type of crop, the trait expressed in the crop, and the pest pressures occurring on the farm. For example, adoption of cultivars with Bt traits has been most rapid and widespread in areas prone to insect infestations that can be curbed by the endotoxins present in GE crops.

The committee chose to concentrate its study on the farm-level effects of GE soybean, corn, and cotton because these crops are grown on nearly half of U.S. cropland (USDA-NASS, 2009b) and because over 80 percent of these crops are genetically engineered (Figure 1-3). The high level of adoption and the large-scale planting of those crops mean they have a substantially greater cumulative impact on farm-level sustainability compared to other GE crops, which may be widely adopted but are planted on few acres or may be adopted by only a small percentage of growers. Additionally, there are GE crops that have been commercialized but were not sold in 2009 for business or legal reasons. Those crops are discussed in the report, but they are not its primary focus (Box 1-2).

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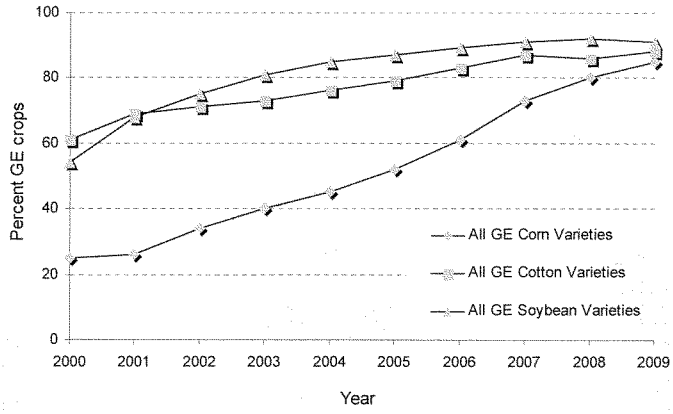


FIGURE 1-3 Nationwide acreage of genetically engineered soybean, corn, and cotton as a percentage of all acreage of these crops.
SOURCE: USDA-NASS, 2001, 2003, 2005, 2007, 2009b.

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BOX 1-2
Other Commercialized Genetically Engineered Crops

GE varieties of crops other than corn, soybean, and cotton have been developed and produced in the United States. However, some are planted on relatively small acreage and often in specific locations (for example, papaya in Hawaii), and others are no longer available commercially (for example, GE potato). These are highlighted below, but they are not the focus of the report because those in production account for only a small percentage of U.S. agriculture in terms of land and revenue, and those not commercially available were only sold for a short time. The latter demonstrates commercial viability can depend on the willingness of farmers to adopt the product and the willingness of processors and consumers to accept it.

Minor Crops Widely Planted in Genetically Engineered Varieties by U.S. Farmers

Canola. HR canola was commercialized in the middle 1990s. It is widely grown in Canada but is a minor crop in the United States. However, since 2005, HR canola has accounted for almost half the acres planted in North Dakota, which makes up more than 90 percent of U.S. canola (USDA-NASS, 2009b). GE glyphosate-resistant and glufosinate-resistant canola cultivars accounted for 65 percent and 32 percent of the canola acres planted in the United States in 2006 (Howatt, personal communication).

Sugar beet. HR sugar beet was approved for commercial use in 1998, but concerns about marketplace acceptance precluded the commercial release of the transgenic cultivars (Duke, 2005). Transgenic glyphosate-resistant sugar beet was commercially grown in 2009 and reportedly was widely adopted (Stachler, personal communication). Economic studies suggested that the transgenic cultivars would improve profitability compared with conventional cultivars (Kniss et al., 2004; Gianessi, 2005). The potential for hybridization between HR sugar beet and weedy beet that occurs in the fields and nearby has led to concerns about future weed problems in Europe (where GE sugar beet is not commercialized), but hybridization is a minor problem in the United States (Stewart et al., 2003; Andersen et al., 2005). Indeed, spatial overlap between sugar beet production and weedy beet is limited to a few California counties (Calflora, 2009).

Papaya. Papaya is a small tree grown throughout the tropics for its fruit. Researchers at Cornell University and the University of Hawaii developed VR papaya by transforming the coat protein gene of the papaya ringspot virus to confer resistance against this devastating pathogen (Fuchs and Gonsalves, 2008). Transgenic papaya was first planted in 1998 in Hawaii, where it has contributed to sustaining the culture of this fruit. About 80 percent of papaya production in Hawaii is from transgenic plants (Fuchs and Gonsalves, 2008; Stokstad, 2008).

Minor Crops with Genetically Engineered Varieties Not Widely Adopted by U.S. Farmers

Squash. Transgenic VR squash lines were transformed with the coat protein gene of the watermelon mosaic virus, zucchini yellow mosaic virus, and cucumber mosaic virus (Fuchs and Gonsalves, 2008). The ZW-20 squash line is resistant to the watermelon and zucchini yellow mosaic virus, and CZW-3 resists the watermelon, zucchini yellow, and cucumber mosaic viruses. ZW-20 and CZW-3 were deregulated in 1994 and 1996, respectively, and commercially grown soon thereafter. Those lines were also crossed to other squash cultivars to produce new lines of VR squash. Transgenic squash accounted for about 12 percent of total U.S. squash production in 2005. Most acreage of transgenic squash is in New Jersey, Florida, Georgia, South Carolina, and Tennessee (Fuchs and Gonsalves, 2008).

Sweet corn. Sweet corn was planted on 617,350 acres in 2008 (USDA-NASS, 2009a). A little less than half, or 246,600 acres, were planted for the fresh market; sweet corn from the remaining acres was for processing. Of the fresh market acres, about 20,000 were planted to GE varieties with high Bt protection against corn earworm and European corn borer and moderate protection against fall armyworm (see Table 1-2; Lynch et al., 1999; Mason, personal communication). Bt sweet corn varieties are typically marketed directly to the consumer;

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processors have been reluctant to purchase sweet corn with GE traits because possible consumer aversion to GE crops could have negatively affected purchases of other products under their brand names (Bradford and Alston, 2004). Commercialized Bt sweet corn also has been engineered to resist glufosinate; however, glufosinate is not registered for use with Bt sweet corn because of concerns about consumer acceptance (Fennimore and Doohan, 2008).

Commercialized Genetically Engineered Crops Not Presently Available

Tomato.[a] The Flavr Savr tomato, developed by the company Calgene, was commercialized in 1994. The genetics of the tomato were engineered to slow the softening of the vegetable during ripening. The trait was developed in a tomato variety usually used for processing. However, a public opposition campaign against GE tomatoes caused some large processors to refuse to purchase the Flavr Savr variety for their products. In response, Calgene tried to sell the variety as a fresh-market tomato, but the vegetable bruised easily. That characteristic caused problems in production, transportation, and distribution. Furthermore, the Flavr Savr did not taste better than its cheaper competitors. Production of the variety was discontinued. Another GE tomato, developed for processing by the company Zeneca, was grown in California in the middle 1990s. Those tomatoes had a similar GE trait for delayed ripening and were processed into tomato paste for sale in the United Kingdom. However, consumer opposition to GE products caused Zeneca to discontinue the sale of the tomato paste in 1999.

Potato. A Bt potato resistant to the Colorado potato beetle was commercialized in 1995. Three years later, the technology developer, Monsanto, introduced a stacked variety that combined the Bt trait with virus resistance. Researchers found the Bt trait protected the potato from insect damage at all stages of the beetle's life (Perlak et al., 1993), and Monsanto scientists noted a large potential for reduction in the use of pesticides to treat insect and virus problems (Kaniewski and Thomas, 2004). However, Monsanto discontinued the sale of GE potatoes in 2001. The cultivars failed to capture more than 2–3 percent of the market for two reasons. First, a new insecticide that controlled the Colorado potato beetle and other pests came on the market at around the same time as GE potatoes; most farmers chose the insecticide over the GE trait (Nesbitt, 2005). Second, potato processors experienced a public-pressure campaign against the use of GE potatoes (Kilman, 2000; Kaniewski and Thomas, 2004). As food companies pledged to use non-GE potatoes in their products, farmers responded to processors' contracts for conventional varieties. Thus, although GE potatoes were technologically successful, they did not survive in the marketplace.

Alfalfa. Alfalfa is an important crop in the United States and is widely cultivated over a broad geographic range (USDA-NASS, 2009b). GE glyphosate-resistant alfalfa was commercialized in 2005, and about 198,000 acres was planted in 2006 (Weise, 2007). However, legal action over concerns about the risk of introgression of the transgene into nontransgenic alfalfa and the inability to mitigate this risk resulted in the termination of further seed sales and planting of glyphosate-resistant alfalfa (Charles, 2007) until USDA completed an environmental impact statement. That statement was released for public comment in December 2009.

[a]Adapted from Vogt and Parish (2001).

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TABLE 1-1 Genetically Engineered Soybean Varieties, by State and United States, 2000–2009

	Herbicide-Resistant Soybean									
State	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
	Percent of all soybean planted									
Arkansas	43	60	68	84	92	92	92	92	94	94
Illinois	44	64	71	77	81	81	87	88	87	90
Indiana	63	78	83	88	87	89	92	94	96	94
Iowa	59	73	75	84	89	91	91	94	95	94
Kansas	66	80	83	87	87	90	85	92	95	94
Michigan	50	59	72	73	75	76	81	87	84	83
Minnesota	46	63	71	79	82	83	88	92	91	92
Mississippi	48	63	80	89	93	96	96	96	97	94
Missouri	62	69	72	83	87	89	93	91	92	89
Nebraska	72	76	85	86	92	91	90	96	97	96
North Dakota	22	49	61	74	82	89	90	92	94	94
Ohio	48	64	73	74	76	77	82	87	89	83
South Dakota	68	80	89	91	95	95	93	97	97	98
Wisconsin	51	63	78	84	82	84	85	88	90	85
Other states[a]	54	64	70	76	82	84	86	86	87	87
United States	54	68	75	81	85	87	89	91	92	91

[a]Includes all other states in soybean estimating program.
SOURCE: USDA-NASS, 2001, 2003, 2005, 2007, 2009b.

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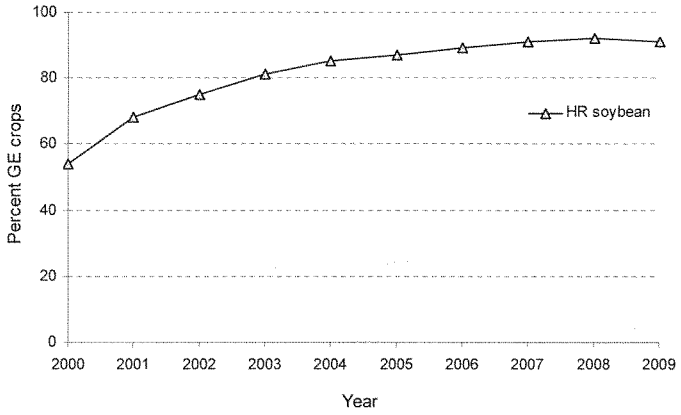


FIGURE 1-4 Herbicide-resistant soybean acreage nationwide.
SOURCE: USDA-NASS, 2001, 2003, 2005, 2007, 2009b.

Corn

The first GE variety of corn, which was commercialized in 1996, expressed a Bt toxin that targeted European corn borer, southwestern corn borer, and several other pests (see Table 1-2). GE corn with resistance to glyphosate was released in 1997, followed by a variety with resistance to glufosinate in the next year (Dill, 2005). An IR variety with a different Bt toxin to combat corn rootworm (*Diabrotica* spp.) was introduced in 2003.

Adoption of HR corn proved slower than that of soybean: only 8 percent of the acreage was planted to HR corn in 2001 (Table 1-3, Figure 1-5). The low adoption rate of HR corn in 2001 was consistent among all U.S. regions. The narrow window of time for glyphosate application to be effective against early-season weed pressure in corn may have deterred farmer adoption (Tharp and Kells, 1999; Johnson et al., 2000; Gower et al., 2003; Knežević et al., 2003; Dalley et al., 2004; Cox et al., 2005). Growers probably relied on traditional strategies for pre-emergence herbicide weed control rather than risk missing the glyphosate application window and ending up with weedier fields and reduced corn yields. Furthermore, lack of market access for HR corn to the European Union provided an added deterrent against early adoption of HR corn in the late 1990s and early 2000s.

Variable insect pressure also delayed the adoption of IR corn, and this resulted in planting of only 19 percent of the acreage to IR corn in 2001 (Table 1-3, Figure 1-5). European corn borer is a key pest in the western Corn Belt region (Pilcher et al., 2002; Hyde et al., 2003; Mungai et al., 2005) but causes only a sporadic problem in the eastern Corn Belt region (Baute et al., 2002; Ma and Subedi, 2005; Cox et al., 2009). Consequently, IR corn acreage ranged from 23 to 30 percent in Iowa, Kansas, Minnesota, Missouri, Nebraska, and South Dakota but from 6 to 11 percent in

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Indiana, Michigan, Ohio, and Wisconsin in 2001 (Table 1-3). Farmers in regions without consistent corn borer infestations probably chose not to adopt IR corn.

TABLE 1-2 Insect Pests of Corn Targeted by Bt Varieties

Common Name	Latin Binomial
Primary Pest	
European corn borer	*Ostrinia nubilalis*
Southwestern corn borer	*Diatraea grandiosella*
Western corn rootworm	*Diabrotica virgifera virgifera*
Northern corn rootworm	*Diabrotica barberi*
Corn earworm	*Helicoverpa zea*
Fall armyworm	*Spodoptera frugiperda*
Black cutworm	*Agristis ipsilon*
Secondary Pest	
Mexican corn rootworm	*Diabrotica virvifera zeae*
Southern cornstalk borer	*Diatraea crambidoides*
Stalk borer	*Papaipema nebris*
Lesser corn stark borer	*Elasmopalpus lignosellus*
Sugarcane borer	*Diatraea saccharalis*
Western bean cutworm	*Richia albicosta*

NOTE: This pest categorization does not describe specific pest pressures in different states or regions. For example, the sugarcane borer is a primary pest of corn in Louisiana.
SOURCE: US-EPA, 2009.

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TABLE 1-3 Genetically Engineered Corn Varieties, by State and United States, 2000–2009

State	Insect-Resistant (Bt) Only										Herbicide-Resistant Only									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Percent of all corn planted										*Percent of all corn planted*									
Illinois	13	12	18	23	26	25	24	19	13	10	3	3	3	4	5	6	12	15	15	15
Indiana	7	6	7	8	11	11	13	12	7	7	4	6	6	7	8	11	15	17	16	17
Iowa	23	25	31	33	36	35	32	22	16	14	5	6	7	8	10	14	14	19	15	15
Kansas	25	26	25	25	25	23	23	25	25	24	7	11	15	17	24	30	33	36	30	29
Michigan	8	8	12	18	15	15	16	19	15	13	4	7	8	14	14	20	18	22	24	20
Minnesota	28	25	29	31	35	33	28	26	19	23	7	7	11	15	17	22	29	32	29	24
Missouri	20	23	27	32	32	37	38	30	27	23	6	8	6	9	13	12	14	19	21	17
Nebraska	24	24	34	36	41	39	37	31	27	26	8	8	9	11	13	18	24	23	24	23
North Dakota[a]						21	29	29	24	22						39	34	37	34	30
Ohio	6	7	6	6	8	9	8	9	12	15	3	4	3	3	4	7	13	12	17	17
South Dakota	35	30	33	34	28	30	20	16	7	6	11	14	23	24	30	31	32	34	30	25
Texas[a]						21	27	22	20	21						42	37	37	31	30
Wisconsin	13	11	15	21	22	22	22	19	14	13	4	6	9	9	14	18	18	23	26	27
Other states[b]	10	11	14	17	19	19	20	20	20	20	6	8	12	17	21	19	25	33	32	30
United States	18	18	22	25	27	26	25	21	17	17	6	7	9	11	14	17	21	24	23	22

State	Stacked-Gene varieties										All GE Varieties									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Percent of all corn planted										*Percent of all corn planted*									
Illinois	1	1	1	1	2	5	19	40	52	59	17	16	22	28	33	36	55	74	80	84
Indiana	*	*	*	1	2	4	12	30	55	55	11	12	13	16	21	26	40	59	78	79
Iowa	2	1	3	4	8	11	18	37	53	57	30	32	41	45	54	60	64	78	84	86

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Kansas	1	1	2	5	5	10	12	21	35	38	33	38	43	47	54	63	68	82	90	91					
Michigan	*	2	2	3	4	5	10	19	33	42	12	17	22	35	33	40	44	60	72	75					
Minnesota	2	4	4	7	11	11	16	28	40	41	37	36	44	53	63	66	73	86	88	88					
Missouri	2	1	2	1	4	6	7	13	22	37	28	32	34	42	49	55	59	62	70	77					
Nebraska	2	2	4	5	6	12	15	25	35	42	34	34	46	52	60	69	76	79	86	91					
North Dakota[a]						15	20	22	31	41						75	83	88	89	93					
Ohio	*	*	*	*	1	2	5	20	37	35	9	11	9	9	13	18	26	41	66	67					
South Dakota	2	3	10	17	21	22	34	43	58	65	48	47	66	75	79	83	86	93	95	96					
Texas[a]						9	13	20	27	33						72	77	79	78	84					
Wisconsin	1	1	2	2	2	6	10	22	35	37	18	18	26	32	38	46	50	64	75	77					
Other states[b]	1	1	2	2	6	6	10	14	22	28	17	20	27	36	46	44	55	67	74	78					
United States	1	1	2	4	6	9	15	28	40	46	25	26	34	40	47	52	61	73	80	85					

*Less than 1%.
[a]Estimates published individually beginning in 2005.
[b]Includes all other states in corn estimating program.
SOURCE: USDA-NASS, 2001, 2003, 2005, 2007, 2009b.

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In 2002, stacked hybrids were introduced, and this led to a further increase in acreage of GE corn. The increasing rate of adoption of stacked hybrids—2 percent in 2002 and 46 percent in 2009, with all major corn states above 30 percent (Table 1-3)—reflects the popularity of these traits and the lack of nonstacked GE traits in the seed marketplace. By 2009, 85 percent of U.S. corn acreage was planted with some type of GE seed; more than half these acres were in stacked varieties (Figure 1-5). In addition, by 2009, all major corn-growing states had GE acreage exceeding 70 percent except Ohio (67 percent); thus, adoption of IR corn is no longer region-specific (Table 1-3). Farmers' preference for multiple traits explains in part the lower rates of adoption of HR-only and IR-only varieties of corn compared with the rates of adoption of HR soybean (Figure 1-4).

Corn rootworm is a destructive and consistent pest in all regions of the United States that have continuous corn fields (and in some regions where corn is planted in fields after soybean). Bt corn for control of corn rootworm, especially western corn rootworm, has contributed to increased acreage of GE corn since its introduction in 2003 because growers preferred IR corn to the use of soil-applied insecticides or the use of insecticide and fungicide applied to seed at 1.25 mg of active ingredient[1] per seed. Bt corn hybrid seed for corn rootworm control is sold with only 0.25 mg of active ingredient per seed of insecticide and fungicide for control of secondary pests[2] and soil-borne pathogens. Growers can choose to add this feature for an additional cost to non-GE or HR corn hybrid seed. Thus, GE corn with the Bt trait for corn rootworm control and lower levels of seed-applied insecticide and fungicide substituted for the control tactics in continuous corn in the 1980s and 1990s of soil-applied insecticides for rootworm control and seed-applied products with higher toxicity[3] for secondary pest control, which growers had to manually apply to the seed. In-plant resistance for rootworm control with low levels of insecticide already applied to the seed by professional seed handlers for control of secondary corn pests is safer for the farmers who plant the crops and for the environment.

[1]The *active ingredient* is the material in the pesticide that is biologically active. The active ingredient is typically mixed with other materials to improve the pesticide's handling, storage, and application properties.

[2]Examples include click beetles (*Alaus oculatus*), scarab beetles (*Scarabaeus sacer*), seed corn maggot (*Delia platura),* and wireworms *(Melanotus* spp).

[3]Examples include O,O-diethyl 0-2-isopropyl-6-methyl(pyrimidine-4-yl) phosphorothioate (commonly marketed as Diazinon); N-trichtoromethylthio~cyclohexene-1,2-dicarboximide (Captan); and gamma-hexachlorocyclohexane (Lindane).

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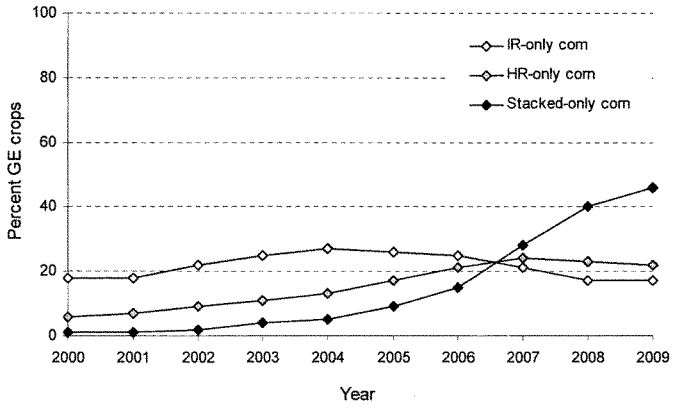


FIGURE 1-5 Genetically engineered corn acreage trends nationwide.
SOURCE: USDA-NASS, 2001; 2003, 2005, 2007, 2009b.

Cotton

Commercialized in 1996, IR cotton rapidly gained substantial market share because of its control of tobacco budworm, pink bollworm, and cotton bollworm (Table 1-5). GE glyphosate-resistant cotton, introduced in 1997, also proved popular with farmers because weed management has traditionally been more challenging in cotton than in many other field crops (Jost et al., 2008). The stacked Bt-glyphosate-resistant variety was introduced in 1997. By 2001, GE cotton had captured 69 percent of the acreage: 32 percent HR-only, 13 percent IR-only, and 24 percent stacked varieties (Table 1-4, Figure 1-6). Farmers in the southeast Cotton Belt adopted GE varieties more rapidly (78–91 percent in Arkansas, Georgia, Louisiana, Mississippi, and North Carolina) compared with those in Texas (49 percent) and California (40 percent), reflecting the lower insect pressure in the latter two states, especially California (only 11 percent IR and 2 percent stacked varieties).

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TABLE 1-4 Insect Pests of Cotton Targeted by Bt Varieties

Common Name	Latin Name
Primary Pest	
Cotton bollworm	*Helicoverpa zea*
Tobacco budworm	*Heliothis virescens*
Pink bollworm	*Pectinophora gosypiella*
Secondary Pest	
Salt marsh caterpillar	*Estigmene acrea*
Cotton leaf perforator	*Bucculatrix thurberiella*
Soybean looper	*Pseudoplusia includens*
Beet armyworm	*Spodoptera exigua*
Fall armyworm	*Spodoptera frugiperda*
Yellowstriped armyworm	*Spodoptera ornithogalli*
European corn borer	*Ostrinia nubilalis*

NOTE: This pest categorization does not describe specific pest pressures in different states or regions. For example, the cotton bollworm and tobacco budworm are minor pests of cotton in Arizona.
SOURCE: US-EPA, 2009.

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TABLE 1-5 Genetically Engineered Upland Cotton Varieties, by State and United States, 2000–2009

State	Insect-Resistant (Bt) Only										Herbicide-Resistant Only									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Percent of all upland cotton planted										*Percent of all upland cotton planted*									
Alabama[a]						10	10	10	18	13						28	25	25	15	18
Arkansas	33	21	27	24	34	42	28	32	30	28	23	29	37	25	15	12	21	16	4	5
California	3	11	6	9	6	8	9	4	7	8	17	27	26	27	39	40	40	51	45	54
Georgia	18	13	8	14	13	29	19	17	19	20	32	43	55	32	23	11	13	10	5	7
Louisiana	37	30	27	30	26	21	13	17	19	20	13	14	9	15	7	10	13	11	6	10
Mississippi	29	10	19	15	16	14	7	16	19	14	13	15	22	16	23	23	22	19	13	16
Missouri[a]						20	32	13	12	18						59	40	63	68	29
North Carolina	11	9	14	16	18	17	19	13	19	15	29	37	27	29	27	24	19	16	14	13
Tennessee[a]						13	16	10	10	7						8	10	17	14	10
Texas	7	8	7	8	10	14	18	16	16	15	33	35	40	39	40	35	34	36	31	31
Other states[b]	17	18	19	18	22	18	21	27	22	24	21	33	35	32	24	24	24	20	20	17
United States	15	13	13	14	16	18	18	17	18	17	26	32	36	32	30	27	26	28	23	23

State	Stacked-Gene Varieties										All GE Varieties									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Percent of all upland cotton planted										*Percent of all upland cotton planted*									
Alabama[a]						54	60	60	65	60						92	95	95	98	91
Arkansas	14	28	26	46	45	42	45	47	64	64	70	78	90	95	94	96	94	95	98	97
California	4	2	1	3	7	5	8	6	8	11	24	40	33	39	52	53	57	61	60	73
Georgia	32	29	30	47	58	55	64	68	73	70	82	85	93	93	94	95	96	95	97	97

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Louisiana	30	47	49	46	60	64	68	68	73	63	80	91	85	91	93	95	94	96	98	93						
Mississippi	36	61	47	61	58	59	69	62	66	63	78	86	88	92	97	96	98	97	98	93						
Missouri[a]						16	25	23	19	51						95	97	99	99	98						
North Carolina	36	38	45	48	46	54	60	64	62	68	76	84	86	93	91	95	98	93	95	96						
Tennessee[a]						75	67	71	73	80						96	93	98	97	97						
Texas	6	6	4	6	8	14	18	28	31	35	46	49	51	53	58	63	70	80	78	81						
Other states[b]	36	33	32	38	45	46	45	42	48	49	74	84	86	88	91	88	90	89	90	90						
United States	20	24	22	27	30	34	39	42	45	48	61	69	71	73	76	79	83	87	86	88						

[a]Estimates published individually beginning in 2005.
[b]Includes all other states in upland cotton estimating program.
SOURCE: USDA-NASS, 2001, 2003, 2005, 2007, 2009b.

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A new HR variety introduced in 2006 provided growers with a wider window for glyphosate application and the possibility of using higher glyphosate dosages (Mills et al., 2008). At around the same time, IR cotton with two Bt endotoxins was commercialized and offered improved control of cotton bollworm, increased protection against such secondary pests as beet armyworm and soybean looper, and advantages in resistance management (Mills et al., 2008; Siebert et al., 2008). The introduction of the improved traits alone or in stacked cultivars contributed to the increase in GE cotton to 88 percent in 2009; 23 percent HR-only, 17 percent IR-only, and 48 percent stacked (Table 1-5). As in 2001, farmers in the southeastern states had a higher adoption rate of GE cotton in 2009 (91 percent or greater) than Texas (81 percent) and California (73 percent). Pink bollworm and cotton bollworm are not major insect pests in California, so adoption of IR cotton (8 percent) and stacked varieties (11 percent) are particularly low; HR cotton (54 percent) makes up most of GE cotton in California.

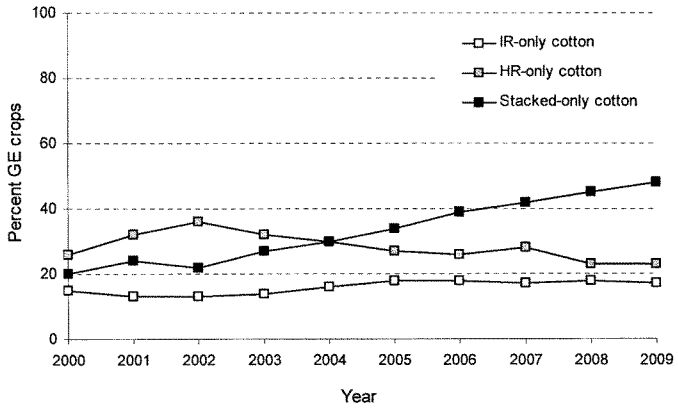


FIGURE 1-6 Genetically engineered cotton acreage trends nationwide.
SOURCE: USDA-NASS, 2000-2008, 2001, 2003, 2005, 2007, 2009b.

An Early Portrait of Farmers who Adopt Genetically Engineered Crops

A study of cotton farmers' planting decisions in four southeastern U.S. states in 1996 and 1997 provided early evidence on the various factors that influenced the choice to adopt transgenic cotton (Marra et al., 2001). The growers were asked about their human capital (stock of knowledge and ability), farm-specific characteristics, reasons for adopting or not adopting Bt cotton in 1996, and the pest-control regimens that they used on both their conventional and their Bt cotton acres (if applicable), including amounts and types of insecticides applied and their

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costs. Comparing the farmers' actions on fields planted to Bt and non-Bt cotton on the same farm controlled for variation in management, land quality, and machinery complement.

The study found that one measure of human capital that was associated with a higher likelihood of adopting Bt cotton was experience (number of years of growing cotton). The age of the farmer was not significant. The propensity to adopt because of higher profit potential of genetic-engineering technology—related to higher yields, decreased costs, or both—was also affirmed by the responding farmers. They reported higher yields on their Bt acres than on their non-Bt acres (6.58 lb/acre more on fields with Bt cotton than those without in the Upper South and 16.43 lb/acre more in the Lower South) and large reductions in pesticide costs in both regions (about $6.00/acre less for fields with Bt cotton in the Upper South and about $10.00/acre less in the Lower South). Similarly, farmers who had previously experienced a high degree of pest infestation or pest resistance to currently used pesticides were more inclined to grow Bt cotton. Adopters reported higher past boll damage (7 percent higher on average compared with nonadopters) and higher incidence of past pest resistance to conventional insecticides (31 percent reported pest resistance compared with 18 percent of nonadopters in the combined sample). Those findings on human capital, yields, and the influence of pest problems are in accord with the explanations for adoption put forth by the diffusion and threshold theories.

Farm characteristics can also play a role in the decision to adopt a new technology. If the technology requires a high initial investment (such as for new machinery), farmers with more acres over which to spread the fixed costs might be more likely to adopt. Although the production technology itself is considered to be scale-neutral (i.e., the technology should not have differential impacts based on the size of the farm operation into which it is adopted), adopters in the study in both regions tended to have much larger farms and to farm more cotton acres than nonadopters; this supports the idea that the costs of learning may not be scale-neutral and thus that there is a possibility that differential farm-level social impacts have been associated with the adoption of GE crops (explained further in Chapter 4).

In 2001, farmers in Indiana, Illinois, Iowa, Minnesota, and Nebraska were surveyed to analyze the differences between adopters and nonadopters in farm and farmer characteristics (Wilson et al., 2005). The responses revealed that farmers growing corn on farms of less than 160 acres planted a greater percentage to GE corn for European corn borer control (54.5 percent) than farmers growing corn on farms of over 520 acres (39.2 percent). The same small–large differential held for aerial application of an insecticide (73.8 percent of farmers with less than 160 acres versus 57.3 percent with more than 520 acres); this suggests that smaller farmers place greater reliance on both chemical and GE controls of European corn borer than larger farmers. Just over one-fifth of the farmers (21.1 percent) reported a yield increase with the use of transgenic corn for European corn borer in all five states, from 11.2 percent in Indiana to 29.9 percent in Minnesota; 2.8 percent reported a yield decrease; and the rest reported no change in yield or that they did not know if there was a change or not. The surveyed farmers' greatest concerns were the ability to sell GE grain (59.3 percent), a market-access factor, and the additional technology fee (57.3 percent), a production-input factor that affected profits. Finally, the responding farmers indicated that a reduction in exposure to chemical insecticide (69.9 percent of the farmers), a personal health concern, and a reduction in insecticides in the environment (68.5 percent), a personal value, were the primary benefits of transgenic corn.

A more recent study of GE-crop adoption pertains to soybean (Marra et al., 2004). Table 1-6 presents the average total number of operated acres, the proportion of operated acres owned, age, education, and income (by category) for the different classes of adopters with the results of

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pairwise t-test results. The t-test results show that adopters (both partial and full) in this survey tended to be younger and operated more acres than nonadopters. Income, education, and percentage of operated acres the farmer owned do not show statistically significant differences among classes of adopters (Marra et al., 2004).

TABLE 1-6 National Soybean Survey Descriptive Statistics by Adoption Category

Farm Characteristics	Nonadopters	Partial Adopters	Full Adopters
Total Operated Acres	916.9[a]	1237.5[b]	1193.4[b]
(N)	(44)	(66)	(136)
Proportion of Acres Owned	0.6[a]	0.5[a]	.05[a]
(N)	(59)	(78)	(167)
Year Born	1944.7[a]	1947.8[b]	1946.3[b]
(N)	(54)	(72)	(150)
Years of Formal Education	13.2[a]	13.7[a]	13.3[a]
(N)	(44)	(62)	(131)
Total Income (by category)	3.3[a]	2.8[a]	3.0[a]
(N)	(34)	(49)	(103)

NOTE: If a superscript letter is different, the mean for this class of adopters is statistically significantly different from the others in that category.
NOTE: Income categories ranged from 1= <$50,000/year to 5 = >$500,000/year.
SOURCE: Marra et al., 2004.

The importance of social networks in influencing patterns of adoption of GE crops has been highlighted in another recent study of the adoption of Bt corn in the Midwest. It described how farmers, whom the author of the study termed *reflexive producers*, negotiate between the advice and claims of experts, who do not farm, and local forms of knowledge that are conveyed by members of farmer networks. The study found that farmers' determination of whether pest problems that require the use of Bt corn exist depended more on local than on expert knowledge (Kaup, 2008).

DETERRENTS TO GENETICALLY ENGINEERED TRAIT DEVELOPMENT IN OTHER CROPS

Soybean, corn, and cotton represent a substantial number of acres planted in the United States, but they do not reflect the diversity of American agriculture. GE varieties have not been developed by private firms for most U.S. crops, in part because the small markets for these crops will not generate sufficient returns on the necessary investment in research, technology commercialization, and marketing infrastructure. Furthermore, concern about selling food with GE-derived ingredients in some markets and the resistance of some grower organizations have limited the commercial application of genetic-engineering technology to just a few crops.

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Market Conditions Influencing the Commercialization of Genetically Engineered Varieties

Most research in and development of GE crops are conducted by private firms. Private companies must produce profits for their shareholders, so the marketability of a crop plays a determining role in decisions as to which GE crops are brought to commercialization. Market size, trait value, regulatory costs, environmental concerns, and technology access influence biotechnology firms' decisions to develop and sell GE seeds.

The market for seeds must be large enough to warrant the investment in commercialization. If markets are too small or are characterized by farmers with low ability to pay for the technology, the benefits to firms are too low to induce them to introduce GE varieties. That is one of the reasons that specialty crops have largely been overlooked in genetic engineering. The VR papaya, for example, was developed through public research. In addition, the number of researchers in these types of crops is considerably smaller and the marketing infrastructure less extensive than for soybean, corn, and cotton. That lack of resources, the diversity of species, the relatively short marketing season, and the small number of planted acres combine to deter private-sector investment in genetic-engineering technology for specialty crops (Bradford and Alston, 2004). To collect sufficient returns, firms instead invest in widely grown crops that have long storage life and that have year-round marketing potential. That generally means that farmers growing such crops have access to genetic-engineering technology, whereas the option is not available to farmers growing specialty crops or crops that are not widely grown in the United States.

The cost of regulatory compliance to ensure that GE crops do not pose unacceptable food safety and environmental risks has become an important component of the overall cost of new biotechnologies (Kalaitzandonakes et al., 2007). These costs may have contributed to limiting the development of GE minor crops, as was the case with pesticide development during the 1970–1990 period. As Ollinger and Fernandez-Cornejo (1995) found, "pesticide regulations have encouraged firms to focus their chemical pesticide research on pesticides for larger crop markets and abandon pesticide development for smaller crop markets." Obtaining regulatory clearance of GE crops in the United States is a long process, and the cost per crop can be very high. Furthermore, for crops with wild, weedy relatives (e.g., wheat), the potential for gene flow raises their environmental risk and expense (see "Gene Flow and Genetically Engineered Crops" in Chapter 2). Large private firms have concluded that investment in less widely grown crops does not generate adequate returns to justify the development and regulatory cost of bringing them to market.

Research and development in genetic-engineering technology have been stimulated by the development of patent protection for GE organisms. Changes in intellectual-property rights (IPR) law in the 1970s and 1980s are largely responsible for creating a profitable environment for biotechnology research. However, that protection may also create constraints on the development of GE varieties of more crops. Companies that control the patents may be unwilling to provide licenses or offer licenses at affordable prices to public-sector researchers or other companies that would like to develop seeds for smaller markets. A similar restriction may occur when university scientists patent genetic material that becomes essential for development of GE crops by other university scientists. Thus, the mechanism that generated the incentives to develop and commercialize genetic engineering may limit its applicability to most crops (Alston, 2004). The influence of IPR on the commercialization of genetically engineered crops will be discussed further in Chapter 4.

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Marketing decisions are also influenced by perceived consumer acceptance of GE products. If technology providers have reason to believe that a GE crop will not be purchased by consumers, the technology will not be commercialized regardless of the potential benefits of the technology to producers. Indeed, a product may even be decommercialized if consumer avoidance, or the fear of it, is high enough. For example, consumer concerns and competing pest-control products caused the GE potato to be discontinued (see Box 1-2). The perceived potential loss of markets has also postponed the commercialization of GE wheat (this is covered further in Chapter 4). Consumers appear to be more accepting of products that are further removed from direct consumption, although additional research is needed in this regard (Tenbült et al., 2008). Thus, companies have been more willing to invest in corn and soybean, which are used primarily for animal feed and processed products, and cotton, a fiber crop. Even though wheat and rice are grains (like corn), are widely planted, and have a considerable storage life, their proximity to the consumer in the food supply chain has contributed to additional pressures on the private sector, which may explain firms' wariness to introduce genetic-engineering technology into them (Wisner, 2006).

Resistance to Genetic-Engineering Technology in Organic Agriculture

As outlined above, genetic-engineering technology is not available to farmers of most crops. However, some producers have chosen not to adopt the technology regardless of its accessibility. That attitude is typified by organic production in the United States.

As American agricultural practices incorporated greater use of synthetic chemicals in the 1950s and 1960s, organic production gained popularity as an alternative farming system. By the 1980s, the organic movement was large enough to justify the establishment of national certification standards. The proliferation of standards, inconsistency in labeling, difficulty in marketing, and inability to police violators of standards prompted organic groups to push for passage of the Organic Foods Production Act (OFPA) of 1990 (Rowson, 1998). The OFPA authorized a National Organic Program (NOP) in the U.S. Department of Agriculture (USDA) to define organic farming practices and acceptable inputs. The act established an advisory group, the National Organic Standards Board (NOSB), to provide recommendations to USDA on the structure and guidelines of the NOP. The NOSB viewed GE organisms as inconsistent with the principles of organic agriculture and recommended their exclusion (Vos, 2000). Opponents of genetic-engineering technology in organic production raised concerns about food safety and environmental effects. They also argued that organic agriculture is based on a set of values that places a high priority on "naturalness" (Verhoog et al., 2003), a criterion that in their view genetic engineering did not meet.

The proposed rule that was issued in 1997 deemed GE seeds permissible in organic agriculture; subsequently, USDA received a record number of public comments, almost entirely in objection to the proposal (Rowson, 1998). In response to the opposition, USDA rewrote the standards. When the NOP final rule went into effect in 2001, GE plants were not considered to be compliant with standards of organic agriculture (Johnson, 2008).

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FROM ADOPTION TO IMPACT

The assessment framework described earlier in this chapter spans all the qualitative dimensions necessary to evaluate the potential sustainability of genetic-engineering technology. Therefore, this report's structure covers environmental, economic, and social changes, and the following chapters report progress and conclusions in these realms.

Environmental Effects

The landscape-level environmental effects of GE crops, both potential improvements and risks, did not receive extensive study when such crops were first planted widely (Wolfenbarger and Phifer, 2000; Ervin et al., 2001; Marvier, 2002). Since then, many studies on nontarget effects, including further studies requested by the U.S. Environmental Protection Agency, have accumulated. Other studies and analyses have related adoption of GE crops to changes in pesticide regimens and tillage practices. However, longitudinal data are still needed to better understand the effects of changes in farm management on environmental sustainability, such as on water quality or on resistance to glyphosate in weeds. Comprehensive evidence on other environmental dimensions—such as some aspects of soil quality, biodiversity, water quality and quantity, and air-quality effects—is also sparse. The environmental effects of farmers' adoption of genetic-engineering technology are discussed in Chapter 2.

Economic Effects

The economic effects of genetic-engineering technology in agriculture, which are addressed in Chapter 3, stem from effects on crop yields; the market returns received for the products; reductions or increases in production inputs and their prices, such as the costs of GE seeds and pesticides; and such other effects as labor savings that permit more off-farm work or that result in changes in yield risk. Those effects have received considerable study, particularly in the early stages of adoption of GE crops. However, recent information is sparse even though new GE varieties continue to be introduced. Less farm-level economic analysis has been conducted, perhaps because of the near dominance of the technologies in soybean, cotton, and corn production, because serious production or environmental problems have not surfaced, and because there is less interest for conducting additional research in a well-studied arena. More extensive studies of some economic effects, such as those on yield, have been conducted more recently in developing countries than in mature markets such as the United States.

Social Effects

The social effects of the adoption or nonadoption of genetic-engineering technology have not been studied as extensively as those attributed to previous waves of technological development in agriculture, even though earlier studies demonstrated that revolutionary agricultural technologies generally have substantial impacts at the farm or community level (Berardi, 1981; DuPuis and Geisler, 1988; Buttel et al., 1990) and that there was a high expectation that genetic-engineering technology would also have substantive and varied social impacts (Pimentel et al., 1989). It is thus surprising that there has been relatively little research on the ethical and

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socioeconomic effects of the adoption of agricultural biotechnology at the farm or community level (e.g., Buttel, 2005). A few studies have explored the economic effects of structural changes (integration and concentration) in the seed and agrichemical industries (Hayenga, 1998; Brennan et al., 2000; Fulton and Giannakas, 2001; Fernandez-Cornejo and Schimmelpfennig, 2004; Fernandez-Cornejo and Just, 2007). However, though the issue of how farmers might be socially impacted by the increasing integration of seed and chemical companies was first raised more than 20 years ago (Hansen et al., 1986), the organizations responsible for conducting or sponsoring research on the effects of genetic-engineering technology have generally fallen short of promoting the comprehensive and rigorous assessment of the possible social and ethical effects of GE-crop adoption. That responsibility rests not only with federal agencies (Kinchy et al., 2008) but with state governments, universities, nongovernment organizations, and the private for-profit sector. The absence of such research reduces our ability to document what the effects of the adoption of genetic-engineering technology have been on farm numbers and structure, community socioeconomic development, and the health and well-being of farm managers, family members, and hired farm laborers. A particularly significant question that has not been adequately assessed is whether the adoption of GE crops has exacerbated, alleviated, or had a neutral effect on the steady decline of farm numbers and the vitality of rural communities often associated with the industrialization of U.S. agricultural production. Because of the comparative dearth of empirical research findings on the social impacts of GE-crop adoption in the United States, we offer in Chapter 4 a discussion of the potential effects of the introduction of genetic-engineering technologies on farming-system dynamics in the form of testable hypotheses and piece together the ancillary literature on documented social effects, such as legal disputes.

CONCLUSION

Genetic-engineering technology has been built on centuries of plant-breeding experiments, research, and technology development. Commercialized applications have focused on pest management, primarily through resistance to the herbicide glyphosate and the incorporation of endotoxins that are lethal to some insect pests. Those traits have provided farmers of soybean, corn, and cotton additional tools for combating pests. The popularity of GE crops is evidenced by their widespread adoption by farmers. In the following three chapters, we examine how their adoption has changed or reinforced farming practices and what implications the changes have for environmental, economic, and social sustainability at the farm level. At the close, we identify remaining challenges and opportunities for GE crops in the United States and draw conclusions and recommendations for increasing their contributions to farm sustainability.

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2

Environmental Impacts of Genetically Engineered Crops at the Farm Level

The environmental impacts of planting genetically engineered (GE) crops occur within the context of agriculture's general contribution to environmental change. Agriculture has historically converted biologically diverse natural grasslands, wetlands, and native forests into less diverse agroecosystems to produce food, feed, and fiber. Effects on the environment depend on the intensity of cultivation over time and space; the inputs applied, including water, fertilizer, and pesticides; and the management of inputs, crop residue, and tillage. With 18 percent of the land area in the United States planted to crops and another 26 percent devoted to pastures (FAO, 2008), the huge scale of these impacts becomes obvious. In general, tillage, crop monoculture, fertilizers, and pesticide use often have adverse effects on soil, water, and biodiversity. Agriculture is the leading cause of water-quality impairment in the United States (USDA-ERS, 2006). No-tillage systems, crop rotations, integrated pest management, and other environmentally friendly management practices may ameliorate some of the adverse impacts, but the tradeoff between agricultural production and the environment remains. With agricultural lands approaching 50 percent of U.S. land, developing more ecologically and environmentally sound agricultural management practices for crops, soil, and water is a central challenge for the future (Hanson et al., 2008). Against that backdrop, we evaluate the impact of GE crops on the environmental sustainability of U.S. farms.

This chapter examines the changes in farm practices that have accompanied the adoption of GE crops and the evidence on how such adoption affects the environment. It addresses impacts at the individual farm level and also at the landscape level, given that impacts from individual farms accumulate and affect other farms and their access to communal natural resources in the region. The use of GE crops has altered farmers' agronomic practices, such as tillage, herbicides, and insecticides; these alterations have implications for environmental sustainability both on and off the farm, which are evaluated to the extent possible at this point in time (Box 2-1). In particular, we examine the effects of the adoption of GE crops on soil quality, biodiversity, and water quality.

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BOX 2-1
Limitations to Evaluating the Magnitude of Environmental Effects

Although environmental risk assessment is conducted for all GE varieties before regulatory approval, in some cases, the absence of environmental monitoring at the landscape level prevents calculating the magnitude of effects (e.g., water quality) following commercialization. Where monitoring data on agricultural practices are available (e.g., tillage practices, pesticide use), simple correlations of the adoption rates with trends in agricultural practices do not capture the complexity required to quantify the magnitude of any environmental effect. The lack of spatially-explicit data linking the use of GE crops with data-monitoring agricultural practices stymies any accurate calculation of the magnitude of environmental effects at national or even regional levels (NRC, 2002). Environmental consequences of agricultural practices can vary greatly at a sub-regional scale. For example, the adoption of a herbicide-resistant crop may facilitate use of no-till practices, but the environmental effects of no-till practices depend on existing soil texture, structure, and erosion potential for each individual farm. Though models may exist to quantify soil retention given erosion potential, what amount of retention can be attributed to HR crops requires two additional calculations:

1. Quantifying to what extent HR crops caused the adoption of conservation tillage practices, given that there is a two-way relationship, and
2. Spatially linking the adoption of HR crops with data on the occurrence of Highly Erodible Land, something not feasible without spatially-explicit data.

Similarly, weed and pest control measures fluctuate from year to year and crop to crop, as have the choices of active ingredients. Determining the extent to which adoption of GE crops replaced specific pesticides over time requires incorporating a suite of factors, such as changes in pest pressure or pest-management strategies (e.g., see footnote on boll weevil eradication program), tillage practices, technology, and public policy (e.g., pesticide regulation, government programs) (Fernandez-Cornejo et al., 2009). Spatial data on the evolution of weed resistance are also lacking, thus preventing any calculation of environmental consequences of the declining effectiveness of glyphosate with glyphosate-resistant crops.

ENVIRONMENTAL IMPACTS OF HERBICIDE-RESISTANT CROPS

The adoption of herbicide-resistant (HR) crops has affected the types and number of herbicides and the amount of active ingredient applied to soybean, corn, and cotton. This section first examines the substitution of glyphosate for other herbicides that has taken place and how the use of HR crops has interacted with tillage practices. It then assesses ecological effects of those changes on soil quality, water quality, arthropod biodiversity, and weed communities. Lastly, the implications for weed management in cropping systems with HR crops are considered, especially for systems in which glyphosate-resistant weeds evolve.

Herbicide Substitution

A higher proportion of herbicide-resistant GE soybean has been planted than of any other GE crop in the United States. Adoption has exceeded 90 percent of the acres planted to soybean by U.S. farmers (Figure 2-1). HR cotton acreage reached 71 percent in 2009 (Figure 2-2), while

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planted HR corn acres were 68 percent that year (Figure 2-3). The HR crops planted thus far have altered the mix of herbicides used in cropping systems and allowed the substitution of glyphosate for other herbicides. Figures 2-1 through 2-3 summarize the trends in the use of glyphosate and other herbicides on corn, soybean, and cotton (expressed in pounds per planted acre of these crops) and the adoption of HR corn, soybean, and cotton (Fernandez-Cornejo et al., 2009). It is important to recognize that, depending on the metrics used, the substitution of glyphosate for other herbicides has resulted in the use of fewer alternative herbicides by growers of HR crops. However, glyphosate is often applied in higher doses and with greater frequency than the herbicides it replaced. Thus, the actual amount of active ingredients (glyphosate and other herbicides) applied per acre actually increased from 1996 to 2007 in soybean (Figure 2-1) and cotton (Figure 2-2) but decreased over the same period in corn (Figure 2-3).

Glyphosate is reported to be more environmentally benign than the herbicides that it has replaced (Fernandez-Cornejo and McBride, 2002; Cerdeira and Duke, 2006). It binds to soil rapidly (preventing leaching), it is biodegraded by soil bacteria, and it has a very low toxicity to mammals, birds, and fish (Malik et al., 1989). Glyphosate can be detected in the soil for a relatively short period of time compared to many other herbicides, but is essentially biologically unavailable (Wauchope et al., 1992). Formulations that contain the surfactant polyoxyethylene amine can be toxic to some amphibians at environmentally-expected concentrations and may affect aquatic organisms under some environmental conditions (Folmar et al., 1979; Tsui and Chu, 2003; Relyea and Jones, 2009); however, these formulations are labeled for terrestrial uses only with restrictions with respect to waterways. The greater use of postemergence glyphosate applications has been accompanied by modifications of agronomic practices, particularly with regards to weed management and tillage. The interactions of those practices have implications for environmental sustainability.

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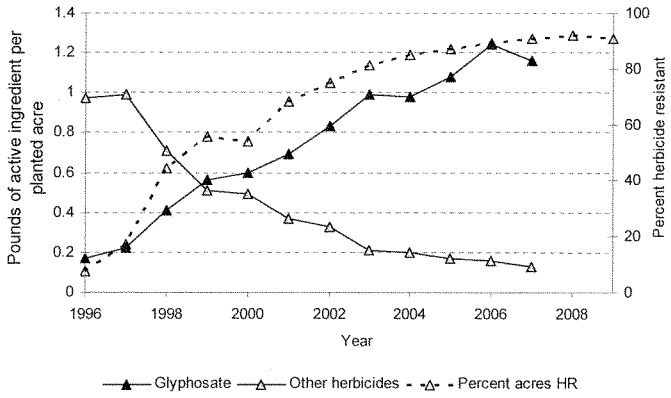


FIGURE 2-1 Application of herbicide to soybean and percentage of acres of herbicide-resistant soybean.
NOTE: The strong correlation between the rising percentage of herbicide-resistant (HR) soybean acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

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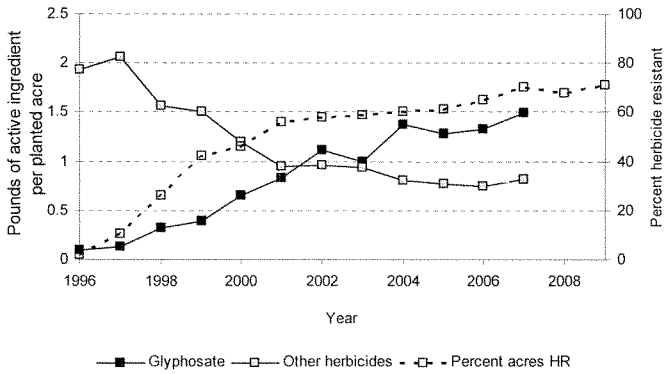


FIGURE 2-2 Application of herbicide to cotton and percentage of acres of herbicide-resistant cotton.
NOTE: The strong correlation between the rising percentage of herbicide-resistant (HR) cotton acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

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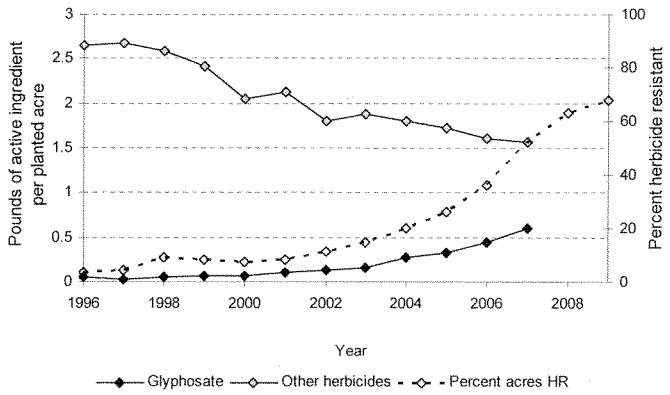


FIGURE 2-3 Application of herbicide to corn and percentage of herbicide-resistant corn.
NOTE: The strong correlation between the rising percentage of herbicide-resistant (HR) corn acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

Tillage Practices

Tillage is one process used by farmers to prepare the soil before planting. In conventional tillage, all postharvest residue is plowed into the soil to prepare a clean seedbed for planting and to reduce the growth of weeds; in conservation tillage, at least 30 percent of the soil surface is left covered with crop residue after planting. In the 1970s and 1980s, innovations in cultivators and seeders enabled farmers to plant seeds at a reasonable cost with residue remaining on the field. Those developments encouraged the adoption of one form of conservation tillage called no-till, in which the soil and surface residue from the previously harvested crop are left undisturbed as the next crop is seeded directly into the soil without tillage. After soil-conservation policy was incorporated into the Food Security Act of 1985, conservation tillage accelerated in the 1990s (Figure 2-4). The introduction of HR soybean and cotton has supported the trend because the use of glyphosate allowed weeds to be controlled after crop emergence without the need for tillage to disrupt weed development before or after planting. Indeed, in the last 10 years, the use of conservation tillage has continued to increase, with the exception that it has remained constant in the case of corn (Figure 2-4).[1]

The adoption of conservation tillage practices by U.S. soybean growers increased from 51 percent of planted acres in 1996 to 63 percent in 2008 (Figure 2-4), or an addition of 12 million

[1]More information on different types of tillage systems can be found in Appendix B.

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acres. The adoption of no-till practices accounted for most of the increase and was used on 85 percent of these additional 12 million acres. Over the same time period, the acreage planted to soybean increased at most nine million acres. In cotton there was a doubling of the percentage of acres managed using conservation tillage from 1996 to 2008, and no-till is the predominant conservation tillage practice (Figure 2-4). Cotton acreage declined over the same time period. For corn between 1996 and 2008, an additional 4.8 million acres of corn were planted. At the same time, the use of conservation tillage practices remained at a fairly constant 40 percent of planted acreage (Figure 2-4). No-till practices increased by 4 percent over the same time period (4.3 million acres) but this was disproportionate relative to overall increases in conservation tillage practices (1.9 million acres), indicating that farmers converted from other conservation tillage practices to no-till.

According to U.S. Department of Agriculture (USDA) survey data for 1997, a larger share of acreages planted to HR soybean was managed with conservation tillage than was planted to conventional soybean (Fernandez-Cornejo and McBride, 2002)—about 60 percent versus about 40 percent (Figure 2-5). The difference in the use of no-till between adopters and nonadopters of HR soybean was even more pronounced: 40 percent of acres planted with HR soybean were under no-till, double the corresponding share of acres of non-GE soybean under no-till management practices (Fernandez-Cornejo and McBride, 2002).

From the perspective of farmer decision-making, the availability of HR technology may affect the adoption of conservation tillage, and the use of conservation tillage may affect the decision to adopt HR crops. Several economists have tried to understand how closely the two decisions are linked. An econometric model developed to address the simultaneous nature of the decisions was used to determine the nature of the relationship between the adoption of GE crops with HR traits and no-till practices on the basis of 1997 national survey data on soybean farmers (Fernandez-Cornejo et al., 2003). Farmers using no-till were found to have a higher probability of adopting HR cultivars than farmers using conventional tillage, but using HR cultivars did not significantly affect no-till adoption. That result suggested that farmers already using no-till incorporated HR cultivars seamlessly into their weed-management program; but the commercialization of HR soybean did not seem to encourage the adoption of no-till, at least at the time of the survey.

More recently, however, Mensah (2007) found a two-way causal relationship on the basis of more recent data. Using a simultaneous-adoption model and 2002 survey data on soybean farmers, Mensah found that farmers who adopted no-till were more likely to adopt HR soybeans *and* that farmers who adopted the HR technology were more likely to adopt no-till practices.

In the case of cotton, the evidence also points toward a two-way causal relationship. Roberts et al. (2006) evaluated the relationship between adoption of HR cotton and conservation tillage practices in Tennessee from 1992 to 2004. Using two methods,[2] they found that the adoption of HR cotton increased the probability that farmers would adopt conservation tillage and conversely that farmers that had previously adopted conservation tillage practices were more likely to adopt HR cotton. Thus, the adoption of no-till practices and the adoption of HR cotton are complementary practices.

[2]An application of Bayes's theorem and a two-equation logit model.

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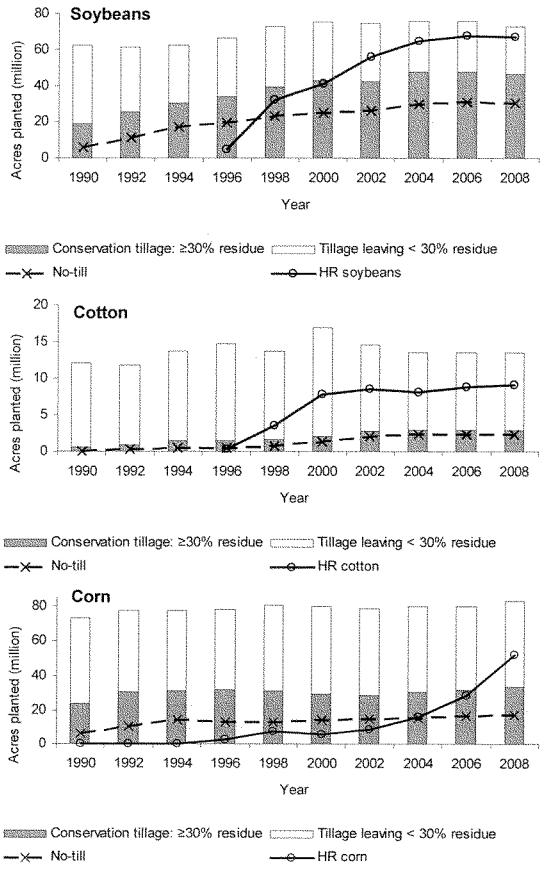


FIGURE 2-4 Trends in conservation tillage practices and no-till for soybean, corn and cotton, and adoption of herbicide-resistant crops since their introduction time in 1996.
SOURCE: CTIC, 2009; USDA-ERS, 2009.

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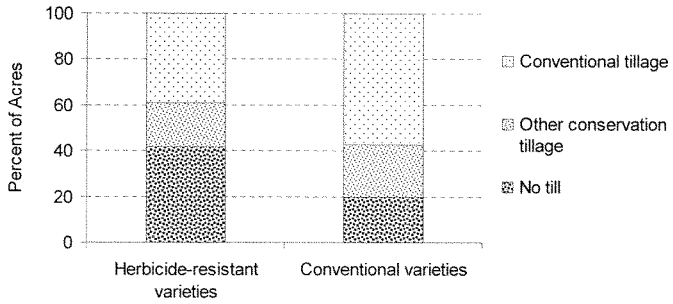


FIGURE 2-5 Soybean acreage under conservation tillage and no-till, 1997.
SOURCE: Adapted from Fernandez-Cornejo and McBride, 2002.

Kalaizandonakes and Suntornpithug (2003) also studied the simultaneous adoption of HR and stacked cotton varieties and conservation tillage practices on the basis of farm-level data. They concluded that conservation tillage practices both encouraged the adoption of HR and stacked cotton varieties and were encouraged by their adoption. Using state-level data for 1997–2002 and using a simultaneous-equation econometric model, Frisvold et al. (2007) studied the diffusion of HR cotton and conservation tillage. They found strong complementarity between the two practices and rejected the null hypothesis that the diffusion of one is independent of the diffusion of the other. They also observed that an increase in the probability of adoption of HR cotton increased the probability of adoption of conservation tillage and vice versa.

Thus, most empirical evidence points to a two-way causal relationship between the adoption of HR crops and conservation tillage.[3] Farmers using conservation tillage practices are more likely to adopt HR crop varieties than those using conventional tillage, and those adopting HR crop varieties are more likely to change to conservation tillage practices than those who use non-HR cultivars. The analytical techniques used do not reveal the relative strength of each causal linkage, so it is not clear which factor (adoption of HR varieties or use of conservation tillage) has a greater influence on the other.

Soil Quality

The relationship between the adoption of conservation tillage practices and the adoption of HR crops is relevant to farm sustainability because conservation tillage has fewer adverse environmental impacts than conventional tillage (reviewed by Uri et al., 1999). On the farm, conservation tillage reduces soil loss from erosion, increases water infiltration, and can improve

[3]Most published evidence is for the cases of soybean and cotton given that extensive adoption of HR corn is relatively more recent (HR corn adoption only exceeded 20 percent of corn acreage in 2005).

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soil quality and moisture retention (reviewed by Uri et al., 1999; Holland, 2004). Corn and soybean are grown in regions where highly erodible land is common, and conversion to conservation tillage for these crops results in substantial reduction in soil loss and wind erosion even on non-highly erodible land (Uri et al., 1999). Leaving more crop residue on fields strengthens nutrient cycling and increases soil organic matter, a key component of soil quality (reviewed by Blanco-Canqui and Lal, 2009). Soil organisms decompose plant residue, and this, in turn, cycles nutrients and improves soil structure. In general, soil organisms have greater abundance or biomass in no-till systems than in conventional tillage systems because soil is disturbed less (reviewed by Wardle, 1995; Kladivko, 2001; Liebig et al., 2004).

In addition to tillage, the use of herbicides can affect soil quality through their impact on soil organisms, so interpreting the effects of HR crops on soil quality requires an understanding of how tillage practices interact with herbicide use to influence the soil microorganism community. In laboratory studies, glyphosate can inhibit or stimulate microbial activity, depending on soil type and glyphosate formulation (Carlisle and Trevors, 1986, and references therein). Some microorganisms can use glyphosate as a substrate for metabolism (increased activity); whereas others are susceptible to the herbicide because they have an enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase pathway that glyphosate inhibits. When species-level responses were measured, roots of glyphosate-resistant soybean and corn treated with glyphosate had significantly more colonies of the fungus *Fusarium* than did non-HR cultivars or HR cultivars not treated with glyphosate (Kremer and Means, 2009). In contrast, fluorescent *Pseudomonas* populations, an antagonist of fungal pathogens like *Fusarium*, were significantly lower in soybean that were both glyphosate resistant and treated with glyphosate compared to untreated HR cultivars or a non-HR cultivar treated with other herbicides (Kremer and Means, 2009). Those results indicate a change in the antagonistic relationship between *Fusarium* and *Pseudomonas* attributable to the formulation of glyphosate used. Whether magnitude of change in this antagonistic relationship would have consequences on soil quality of disease control was not a part of the study.

With respect to general microbial activity, three studies in the United States have detected no uniform changes in soil organism profiles in association with tillage or with the use of glyphosate on glyphosate-resistant cropping systems (Liphadzi et al., 2005; Weaver et al., 2007; Locke et al., 2008). Soil microorganisms in fields planted with glyphosate-resistant corn and soybean varieties were similar with and without tillage (Liphadzi et al., 2005). HR fields treated with glyphosate and non-GE fields treated with other herbicides were also similar in soil microbe activity (Liphadzi et al., 2005). On tilled, experimental plots of glyphosate-resistant soybean, transient changes in the soil microbial community were detected in the first few days after application of glyphosate compared to no application (Weaver et al., 2007), but the differences disappeared after 7 days. When there was continuous cotton cropping, soil quality did not differ between HR and non-HR systems. In contrast, soil under continuous HR-corn cropping contained more carbon and nitrogen than soil with non-HR corn (Locke et al., 2008), which would be considered a benign change. Differences in carbon and nitrogen contents could have been due to glyphosate use, but they were also probably influenced by changes in the detrital food web associated with the higher biomass of winter weeds in the HR-corn cropping system (Locke et al., 2008). Subtle differences in the structure of the soil microbial community were also detectable in those same experiments; the significance of the differences for soil quality were not discussed. Thus, species-level studies suggest that glyphosate can alter the microbial composition in the rhizosphere. General studies of the interaction of tillage and glyphosate use in

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HR crops have indicated transient benign effects of glyphosate and neutral, or in one case favorable, effects of conservation tillage on the soil communities in HR crops.

Water Quality

Conservation tillage practices can have off-farm benefits for water quality that are potentially more important than onsite productivity effects (Foster and Dabney, 1995). Because conservation tillage practices improve soil-water infiltration, the volume of runoff is less than when conventional tillage is used. Reduced tillage and no-till practices can improve water quality by reducing the amounts of sediments and sediment-associated chemicals in runoff from farm fields into surface water. Similarly, lower volumes of runoff can decrease the transport of soil nutrients and agricultural inputs, such as fertilizers and pesticides, although the decrease will vary with soil type, tillage practice, and nutrient or pesticide input. For example, although the concentration of herbicide in runoff from no-till fields can be higher than when other conservation tillage practices are used, the total amount of herbicide in runoff may be similar because runoff volume is reduced (Fawcett et al., 1994; Locke and Bryson, 1997; Mickelson et al., 2001; Shipitalo and Owens, 2006; Zeimen et al., 2006). That phenomenon has been observed with the use of glyphosate in no-till fields (Shipitalo et al., 2008).

Studies have suggested that the use of glyphosate poses less risk to water quality than the use of other herbicides; this is attributable in part to the production systems typically used in GE crops and to the physical chemistry and relatively low toxicity of glyphosate (Estes et al., 2001; Wauchope et al., 2002; Peterson and Hulting, 2004). However, there are no regional-scale analyses of the effects of HR-crop adoption on water quality. One study conducted in a small Ohio watershed that compared herbicide runoff in HR and non-HR soybean fields found that the amount of glyphosate in the runoff was nearly one-seventh that of the herbicide metribuzin and about half that of alachlor, even though glyphosate was applied to soybean twice and alachlor and metribuzin once to soybean (Shipitalo et al., 2008). Those results are consistent with known characteristics of glyphosate, which strongly absorbs to soil and has a half-life in soil of 6–60 days, depending on soil characteristics. Microbial processes degrade glyphosate into two metabolites: sarcosine and aminomethylphosphonic acid (AMPA). Sarcosine degrades quickly to carbon dioxide and ammonia. AMPA is more persistent than glyphosate in the soil environment but is considered equally or less toxic (reviewed by Giesy et al., 2000). Numerous studies have documented the occurrence of glyphosate and AMPA in surface waters (Kolpin et al., 2006), but they have rarely been found in groundwater (Borggaard and Gimsing, 2008). Concentrations of glyphosate reported in surface water have not exceeded the maximum contaminant level (MCL) for drinking water set by the U.S. Environmental Protection Agency (EPA); in accordance with World Health Organization recommendations, MCLs have not been set for AMPA (WHO, 2005).

Shifts to conservation tillage attributable to the availability of HR crops have contributed to reductions in soil loss and probably in herbicide runoff. The magnitude and spatial distribution of the benefits is not precisely known, but the implications are that those are important environmental benefits of these cropping systems. However, as discussed later in this chapter (see "Other Shifts in Weed Communities"), some of the environmental benefits may be threatened in the future.

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Arthropod Biodiversity

Changes in herbicide use and tillage practices like those accompanying the adoption of HR crops can affect such organisms as natural enemies of pests or pollinators, which provide ecological services to agriculture. Weeds provide an ecological disservice to farms by competing with crop plants for nutrients and light even at low population densities, but weeds can also support a broad array of nonpest species. Pollinators feed on nectar or use some weeds as hosts for their larval stage; weed species can be food for herbivores that in turn are preyed on by predators that also control pests of crops. In particular, more effective weed management could decrease the abundance of beneficial organisms, depending on the mobility of a species and how closely its resource base is associated with weed abundance. In contrast, the increase in no-till practices that leave more plant material undisturbed in fields may increase the resource base for beneficial insects.

Evidence indicates that the planting of HR cultivars does not consistently affect the weed diversity and abundance that support beneficial species. Whether a farmer used a GE crop or a conventional crop, better weed control has generally reduced the numbers of arthropods and other organisms in corn, sugar beet, and rapeseed fields (Hawes et al., 2003) and decreased the abundance of the predatory big-eyed bug (*Geocoris punctipes*) in soybean fields (Jackson et al., 2003; Jackson and Pitre, 2004). When HR crops improved weed management (decreased weeds), populations of natural enemies and pollinators decreased (Hawes et al., 2003). When conventional weed-management tactics (such as the use of the herbicide atrazine) were more effective at weed control on non-HR corn relative to HR corn, beneficial insect abundance was greater within the HR side of the field where more weeds occurred (Hawes et al., 2003). Subsequent analyses of these same data in more depth have revealed detailed associations between properties of the weed community and the accompanying arthropod food web (Hawes et al., 2009) and strengthened the conclusion that weed management accounts for the relationships observed. However, weed management was not the largest influence on the abundance of beneficial organisms. Rather, there were differences of a factor of 3–10 in abundance among different crops and between early and late in the growing season, compared with differences of a factor of 2 associated with weed management (Hawes et al., 2003).

Weed Biodiversity and Weed Shifts

Crop-production practices inevitably influence the composition of the weed community. Typically, only a few weed species are economically important in a particular crop-production system (Owen, 2001; Tuesca et al., 2001). When a production practice changes, for example, a change in herbicide, it may ultimately select for weed biotypes that are resistant to that herbicide (Baker, 1991). Other elements of production practices that have selective effects on the weed community include harvesting techniques, irrigation, fertilization, planting dates, soil amendments, and tillage (Hilgenfeld et al., 2004; Murphy and Lemerle, 2006; Owen, 2008).

The stronger the selective force of those practices (e.g., the level of disturbance caused by tillage), the more consistent the selective force (e.g., continuous planting of the same crop as opposed to annual crop rotations), and the simpler the selective force (e.g., the recurrent use of one herbicide), the greater the effect on the composition of the weed community (Owen, 2001). Changes in the kinds of weeds that are important locally are termed *weed shifts* (which implies changes in weed species composition) (Givnish, 2001); in the following discussion, weed shifts

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are the ecological process by which an initial weed community is replaced by a new community, including better-adapted species, in response to changes in agricultural practices. Weed shifts are generally followed by a period of stability, given the longevity of weed seeds in the soil, as long as the agricultural systems that resulted in the shift remain constant (Buhler, 1992; Buhler et al., 1997). They are a common and inevitable result of agriculture and are not unique to the adoption of HR crops, but it is essential to understand and manage them well if agriculture is to be productive and sustainable. Such shifts are particularly relevant for managing weeds in HR-crop systems, in which tillage practices and herbicide use both play major roles in shaping the weed community.

Herbicide Resistance in Weeds

The International Survey of Herbicide Resistant Weeds (ISHRW) provides a historical account and extensive list of weeds that have evolved resistance to herbicides (Heap, 2010). Although the ISHRW reflects the efforts of many weed scientists in reporting weed populations that have herbicide resistance, the voluntary basis of the contributions likely results in underestimation of the extent of resistance to herbicides, including glyphosate. The evolution of herbicide-resistant weeds is not unique to the herbicides for which HR traits exist. Currently, 195 species (115 dicots and 80 monocots) have evolved resistance to at least one of 19 herbicide mechanisms of action in at least 347 herbicide-resistant weed biotypes distributed over 340,000 fields (Heap, 2010).

Glyphosate, first commercialized in 1974, has been extensively used for weed control in perennial crops (fruits, trees, nuts, and vines), along roadsides and irrigation canal banks, and in urban areas and national parks (Powles, 2008). The first case of evolved resistance to glyphosate was reported in 1996 in rigid ryegrass (*Lolium rigidum*) (Powles et al., 1998). The glyphosate-resistant population originated in an orchard in a large winter cropping region of southern Australia, where glyphosate had been used intensively for the control of rigid ryegrass for more than 15 years. Since the initial report, at least six other weed species have been reported as resistant to glyphosate in environments where glyphosate-resistant crops were not planted (Powles, 2008; Heap, 2010).

Emergence of Glyphosate-Resistant Weeds in Herbicide-Resistant Crop Fields

Eight or nine species have evolved resistance to glyphosate independently in glyphosate-resistant crops over 13 years in the United States (from 1996 to 2009) (Heap, 2010). Gene flow between HR crops and closely related weed species does not explain the evolution of glyphosate resistance in U.S. fields because sexually compatible weeds are absent where corn, cotton, and soybean are grown in the United States. However, the nearly exclusive reliance on glyphosate for weed control, a practice accelerated by the widespread introduction of glyphosate-resistant crop varieties, has caused substantial changes in weed communities. The first report of glyphosate resistance associated with a GE glyphosate-resistant crop involved horseweed (*Conyza canadensis*) in Delaware (VanGessel, 2001); once resistance evolved, growers found it difficult to control this weed in no-till glyphosate-resistant soybean (VanGessel, 2001). Since the initial report in 2000, glyphosate-resistant populations of horseweed have been documented throughout the Mid-Atlantic, Mid-South, Mississippi Delta, and Midwest states (Heap, 2010). The weed

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grows particularly well in no-till production systems, producing a large number of wind-carried seeds that are dispersed over long distances (Buhler and Owen, 1997; Ozinga et al., 2004).

Subsequent to that discovery in 2000, other weed species have evolved resistance to glyphosate in glyphosate-resistant crops in the United States (Table 2-1). They include two species of pigweed, Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus*),[4] which have become economically important in glyphosate-resistant cotton and soybean production (Zelaya and Owen, 2000, 2002; Culpepper, 2006; Culpepper and York, 2007; Legleiter and Bradley, 2008). Infested areas are increasing rapidly in the Southeast, the Mississippi Delta (Palmer amaranth and Johnsongrass, *Sorghum halepense*), and the Midwest (waterhemp) (Culpepper and York, 2007; Legleiter and Bradley, 2008). Glyphosate-resistant populations of giant ragweed (*Ambrosia trifida*) have been reported in several states (Leer, 2006), primarily in or adjacent to glyphosate-resistant soybean. Kochia (*Kochia scoparia*) with evolved resistance to glyphosate has recently been identified in Kansas (Heap, 2010). Another weed, common lambsquarters (*Chenopodium album*) (Kniss et al., 2004, 2005; Schuster et al., 2007; Scursoni et al., 2007) may have also evolved glyphosate-resistant biotypes (Boerboom, 2005), but it has not yet appeared on the ISHRW list.

TABLE 2-1 Weeds That Evolved Resistance to Glyphosate in Glyphosate-Resistant Crops in the United States

Species	Crop	Location	Acreage[a]
Amaranthus palmeri (Palmer amaranth)	Corn, cotton, soybean	Georgia, North Carolina, Arkansas, Tennessee, Mississippi	200,000–2,000,000
Amaranthus tuberculatus (waterhemp)	Corn, soybean	Missouri, Illinois, Kansas, Minnesota	1,200–11,000
Ambrosia artemisiifolia (common ragweed)	Soybean	Arkansas, Missouri, Kansas	<150
Ambrosia trifida (giant ragweed)	Cotton, soybean	Ohio, Arkansas, Indiana, Kansas, Minnesota, Tennessee	2,000–12,000
Conyza canadensis (horseweed)	Corn, cotton, soybean	14 states	> 2,000,000
Kochia scoparia (kochia)	Corn, soybean	Kansas	51-100
Lolium multiflorum (Italian ryegrass)	Cotton, soybean	Mississippi	1000–10,000
Sorghum halepense (Johnsongrass)	Soybean	Arkansas	Unknown

[a]Minimum and maximum acreages are based on expert judgments provided for each state. The estimates were summed and rounded to provide an assessment of the minimum and maximum acreages in the United States. These values indicate orders of magnitudes but do not provide precise information on abundance of resistant weeds.
SOURCE: Data from Heap, 2010.

[4]In some literature, *Amaranthus tuberculatus* is referred to as *Amaranthus rudis*.

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Other Shifts in Weed Communities

Factors other than the evolution of glyphosate resistance affect the composition of weed species in the field. Changes in the tillage system used in growing HR crops are probably the most important factor in promoting weed shifts because disturbance is a primary selective force (Buhler, 1992). In addition, weeds that escape glyphosate applications by germinating after the last application can have an advantage in glyphosate-resistant crops (Hilgenfeld et al., 2004; Owen and Zelaya, 2005; Puricelli and Tuesca, 2005; Scursoni et al., 2007; Wilson et al., 2007; Owen, 2008). Table 2-2 lists weed species that have been found to be naturally tolerant to the conditions prevalent in the fields where glyphosate-resistant crops are grown and have become more abundant after the widespread adoption of these crops. Shifts in local weed communities have been observed more frequently in glyphosate-resistant cotton and soybean than in glyphosate-resistant corn, probably because glyphosate-resistant cotton and soybean are more widely cultivated than glyphosate-resistant corn (Culpepper, 2006). However, where glyphosate-resistant corn and glyphosate-resistant soybean are commonly rotated (e.g., in the Midwest), strong selection pressure exists for the evolution of glyphosate-resistant weeds because the management tactics vary so little between the two crops.

Farmers' Response to Glyphosate Resistance in Weeds

The evolution of glyphosate resistance in some kinds of weeds and other weed shifts can diminish the technical and economic efficiency of weed control. However, because glyphosate allows producers to control a wide array of weeds conveniently and economically, they have been reluctant to stop using glyphosate-resistant crops and glyphosate when facing control problems arising from a few glyphosate-resistant or naturally glyphosate-tolerant weed species. For controlling problematic weeds, they prefer increasing the magnitude and frequency of glyphosate applications, using other herbicides in addition to glyphosate, or increasing their use of tillage.

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TABLE 2-2 Weeds Reported to Have Increased in Abundance in Glyphosate-Resistant Crops

Species	Crop	Location	Reference
Acalypha spp. (copperleaf)	Soybean	—	Owen and Zelaya, 2005; Culpepper, 2006
Amaranthus tuberculatus (waterhemp)	Soybean	—	Owen and Zelaya, 2005
Amaranthus palmeri (Palmer amaranth)	Cotton	—	Culpepper, 2006
Annual grasses	Cotton	—	Culpepper, 2006
Chenopodium album (common lambsquarters)	Soybean	Iowa, Minnesota	Owen, 2008
Commelina communis (Asiatic dayflower)	Cotton, soybean	Midwest, Midsouth, Southeast	Owen and Zelaya, 2005; Culpepper, 2006; Owen, 2008
Commelina benghalensis (tropical spiderwort)	Cotton	Southeast, Georgia	Owen, 2008; Mueller et al., 2005
Cyperus spp. (nutsedge)	Cotton	—	Culpepper, 2006
Equisetum arvense (field horsetail)	Herbicide-resistant crops	—	Owen, 2008
Oenothera biennis (evening primrose)	Herbicide-resistant crops	Iowa	Owen, 2008
Oenothera laciniata (cutleaf evening primrose)	Soybean	—	Culpepper, 2006
Pastinaca sativa (wild parsnip)	Herbicide-resistant crops	Iowa	Owen, 2008
Phytolacca americana (pokeweed)	Herbicide-resistant crops	—	Owen, 2008
Ipomoea spp. (annual morning glory)	Cotton	—	Culpepper, 2006

For example, soybean growers in Delaware continued planting glyphosate-resistant soybean even in the presence of widespread glyphosate resistance in horseweed (Scott and VanGessel, 2007). Most producers addressed the problem by applying an herbicide with a different mode of action, increasing the frequency of glyphosate applications, or using tillage before planting. Some 76 percent of growers estimated that resistance in horseweed increased their management costs by more than $2.02/acre, and 28 percent reported cost increases of over $8.09/acre (Scott and VanGessel, 2007). Similarly, a survey of 400 corn, soybean, and cotton producers in 17 states found that most would not limit the use of glyphosate-resistant crops when facing problematic glyphosate-resistant weeds (Foresman and Glasgow, 2008). Instead, producers planned to increase the rotation of herbicides, the use of tank-mixes, or the amount of tillage. They expected that additional measures for the control of glyphosate-resistant weeds would cost $13.90–16.30/acre (Foresman and Glasgow, 2008).

In an economic analysis of weed-management costs with a hypothetical reduction of control with glyphosate in three regions of the United States, the projected cost of new resistance-

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management practices for horseweed was $12.33/acre in a cotton–soybean–corn rotation in western Tennessee (Mueller et al., 2005). Additional costs were due to a shift from no-till to conventional tillage for cotton and the need for new preplant herbicides for soybean. The projected cost of new herbicide resistance-management practices for waterhemp was $17.91/acre in a corn–soybean rotation in southern Illinois; this cost resulted from use of different pre-emergence and postemergence herbicides for soybean (Mueller et al., 2005). For cotton grown in Georgia, the extra cost of controlling shifts in tropical spiderwort (*Commelina benghalensis*), a weed that is naturally tolerant to glyphosate, was predicted to be $14.91/acre; an additional herbicide application after cotton emergence explained this cost (Mueller et al., 2005).

Those studies indicate that the evolution of glyphosate resistance and weed shifts could lead to two important changes in practices: increased use of herbicides generally and reductions in conservation tillage (Mueller et al., 2005). Such changes would also increase weed-management costs and reduce producers' profits, and the environmental consequences of those practices, if they were widely adopted by producers of HR crops, would negate the environmental benefits previously achieved.

In summary, most glyphosate-resistant weeds in HR crops are of economic importance in row crops grown in the Southeast and Midwest. The number of weed species evolving resistance to glyphosate is growing (Figure 2-6), and the number of locations with glyphosate-resistant weeds is increasing at a greater rate, as more and more acreage is sprayed with glyphosate. Though the number of weeds with resistance to glyphosate is still small compared to other common herbicides,[5] the shift toward glyphosate-resistant weed biotypes will probably become an even more important component of row-crop agriculture unless production practices (such as recurrent use of glyphosate) change dramatically (Gressel, 1996; Owen and Zelaya, 2005; Johnson et al., 2009).

Implications of Weed Shifts in Herbicide-Resistant Cropping Systems

As noted above, because the adoption of HR crops has facilitated an increase in conservation tillage and reduced the number of herbicides that growers use to control weeds, the selection pressures affecting weed communities has changed. Unsurprisingly, managing weeds through glyphosate applications to HR crops favors the evolution of glyphosate resistance in weeds occurring in these crop fields (Shaner, 2000; Mueller et al., 2005; Foresman and Glasgow, 2008; Powles, 2008). Addressing the problem of resistance—a problem not unique to HR crops—requires careful thought about management practices and other potential solutions based on a clear understanding of how genes that code for resistance are distributed throughout a population of a weed species.

Principles of Population Genetics Underlying Resistance in Weeds

Similar concepts have been used to understand the evolution of resistance to glyphosate in weeds and to the Bt toxin in insects. Population-genetic models and empirical data on factors that

[5]For example, 38 weeds have developed resistance to some acetyl-CoA carboxylase (ACCase), and resistance to some acetolactate synthase (ALS) inhibitors has been documented in 107 worldwide.

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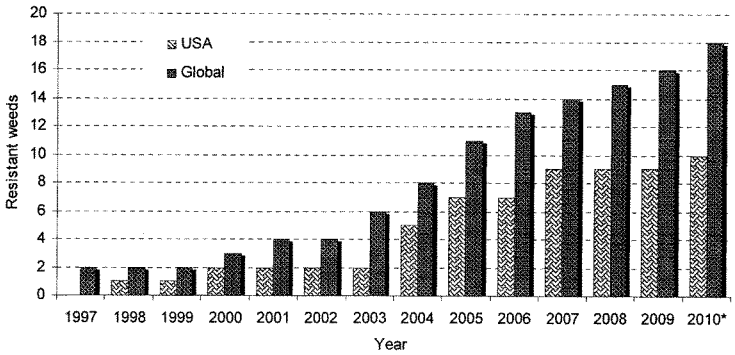


FIGURE 2-6 Number of weeds with evolved glyphosate resistance.
* Weed numbers are updated through March 2010.
SOURCE: Adapted from Heap, 2010.

affect how resistance evolves have been applied to the management of both herbicide-resistant weeds and Bt-resistant insects (Jasieniuk et al., 1996; Werth et al., 2008). However, strategies for delaying the evolution and spread of resistance are not the same because there are important underlying differences in the population genetics of herbicide resistance and insect resistance.

Resistance to herbicides, and in particular to glyphosate, is often conferred by a single nuclear gene (Jasieniuk et al., 1996; Powles and Preston, 2006). Herbicide resistance in weeds is rarely recessive;[6] in all cases studied, resistance to glyphosate was additive to dominant, that is, individuals with a single resistance allele can survive applications of glyphosate (Jasieniuk et al., 1996; Zelaya et al., 2004; Powles and Preston, 2006; Zelaya et al., 2007; Neve, 2008). Furthermore, even if resistance is recessive in some weeds, many weeds are self-pollinating, so a recessive gene for resistance could become homozygous in only a few generations and thus confer resistance to all offspring (Gould, 1995; Jasieniuk et al., 1996). Some agronomically important weeds (such as, pigweed) are dioecious (having separate male and female plants) and thus are cross-pollinated. They have demonstrated the ability to evolve resistance to glyphosate although the genetics of the process have not been described.

Finally, even though the seeds of some weed species can disperse over long distances (Shields et al., 2006), dispersal of viable pollen generally occurs over short distances (Jasieniuk et al., 1996; Roux et al., 2008). Therein lies an important difference between weeds and insects and hence the availability of strategies, such as refuges, to control weed resistance. For all the reasons described above, maintaining a refuge—an area where susceptible weeds are not

[6]Plants carry two alleles (forms) of the same gene for glyphosate resistance. Each allele exerts influence on the nature of that trait; saying that resistance is recessive means that one allele is not sufficient to confer resistance. Offspring that inherit one allele with the resistant trait and one without will not be resistant, while offspring that inherits two of the same form of the allele that confers resistance will be resistant.

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exposed to glyphosate and would persist to interbreed with resistant biotypes—cannot be expected to lower the heritability of herbicide resistance in weeds as it lowers the heritability of Bt resistance in insects targeted by Bt crops (Jasieniuk et al., 1996). The refuge strategy for Bt-resistant insects is discussed later in this chapter (see "Evolution and Management of Insect Resistance").

Although the use of refuges cannot be expected to delay the evolution of glyphosate resistance in weeds, the spread of herbicide resistance can be delayed by reducing the selective differential (the difference in survival and other fitness traits) between individuals with and without resistance alleles (Gressel and Segel, 1990; Jasieniuk et al., 1996; Werth et al., 2008). That can be accomplished by using control practices that kill weeds that have the resistance alleles. For example, the use of tank-mixes that contain two or more herbicides with different modes of action may be effective if the herbicides have high efficacy in controlling the target weeds. Similarly, herbicides with different modes of action or methods that combine herbicides and mechanical weed control (tillage) may be used sequentially to control the same generation (i.e., emergence cohort) of weeds.

The selective differential between individuals with and without resistance alleles can also be reduced by rotating the types of herbicides used to control the target weeds so that selection for resistance to a specific herbicide occurs only in alternate growing seasons (Jasieniuk et al., 1996; Roux et al., 2008). When no fitness costs[7] are associated with resistance, the rotation of herbicides contributes to equalizing the fitness of individuals that are resistant to and susceptible to a herbicide during seasons when the herbicide is not used. Models suggest that the evolution of resistance to the rotated herbicides will be delayed by 1 year for each year that the rotation tactic is used (Maxwell and Jasieniuk, 2000). When fitness costs are associated with resistance to a herbicide (Gressel and Segel, 1990; Jasieniuk et al., 1996; Baucom and Mauricio, 2004), the fitness of individuals that have resistance alleles is lower than the fitness of individuals that do not during seasons when the herbicide is not used. Therefore, herbicide rotation contributes to reducing the selective differential between individuals with and without resistance alleles over time, which may delay the evolution of resistance (Jasieniuk et al., 1996; Roux et al., 2008).

Reduction in the selective differential can be accomplished by rotating the type of crops grown in a field between growing seasons; this may result in drastic changes in the types of herbicides used. Changes in ecological conditions associated with cultivation of different crops could favor declines in particular weed species (which could be resistant or tolerant to glyphosate) or induce competitive disadvantages in herbicide-resistant weeds through negative cross-resistance, in which resistance to one chemical confers hypersensitivity to another chemical (Gressel and Segel, 1990; Boerboom, 1999; Owen and Zelaya, 2005; Beckie et al., 2006; Murphy and Lemerle, 2006).

Developing Weed-Management Strategies for Herbicide-Resistant Crops

How might the various strategies be used in the context of HR cropping systems? Tank-mixes and sequences of herbicides to extend the useful life of herbicides could be employed if

[7]Some genes that confer resistance affect the biological or physiological viability of an organism adversely in absence of a pesticide, and carriers of such a gene tend to become rarer in the population over time. The fitness cost is the extent to which such a penalty on fitness exists.

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crop cultivars that are resistant to two or more herbicides are developed; this strategy is currently favored by biotechnology companies (Duke, 2005; Behrens et al., 2007; Green et al., 2008; Green, 2009). As for using crop rotations, the increasingly common practice of farmers throughout the United States of using glyphosate as the primary or only weed-management tactic in rotations of different glyphosate-resistant crops limits the application of the rotation strategy, even if the change in crop-induced ecological changes might improve weed management. A possible solution could be to combine the rotation of two or more HR cultivars that each can tolerate only one herbicide with the use of a different herbicide at each rotation. For example, different varieties of GE canola (*Brassica napus* L.) grown in the prairie provinces of Canada were engineered for resistance to glufosinate or glyphosate. That allowed producers to include two types of HR canola into a canola–wheat–barley rotation so that canola resistant to glufosinate or glyphosate would be grown only once every 4 years in a particular field (Powles, 2008). In contrast with corn, soybean, and most cotton production, growing crop species like canola, in which hybridization between the crop and weedy relatives is possible, poses a risk of gene flow between the HR crop and the weedy relatives (Beckie et al., 2003; Légère, 2005; see also "Gene Flow Between Genetically Engineered Crops and Related Weed Species").

The same rotation strategy could be used with HR crops that are resistant to two (or more) herbicides; the same crop would be grown twice during the rotation" cycle, but each of the two herbicides that it can resist would be applied only every other year. Genes that confer resistance to some acetyl-CoA carboxylase (ACCase) inhibitors, synthetic auxins (e.g., 2, 4-D), acetolactate synthase (ALS) inhibitors, dicamba, glufosinate, glyphosate, and hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors are the most likely candidates for production of the next generation of HR varieties that are resistant to multiple herbicides (Duke, 2005; Behrens et al., 2007; Green, 2009). So far, weed resistance to glufosinate and HPPD inhibitors has not been reported. Weed resistance to dicamba has not been reported in corn, cotton, or soybean but has appeared in other crops in the United States (Heap, 2010). However, weed resistance to some ACCase inhibitors, synthetic auxins, and ALS inhibitors has been reported in corn, cotton, and soybean (Heap, 2010). Moreover, most weed species that have evolved resistance to glyphosate in fields of HR crops (Table 2-1) also have evolved resistance to ALS inhibitors (Heap, 2010).

From the point of view of herbicide-resistance management and the long-term efficacy of an HR crop, it may be better to engineer a crop for resistance to herbicides that can efficiently control most weeds associated with the crop. For example, genes that confer resistance to ALS inhibitors, to which many weed species are already resistant, could be inferior to genes that confer resistance to dicamba, glufosinate, and HPPD inhibitors to produce durable HR corn, cotton, and soybean resistant to two or more herbicides. Similarly, care should be taken to engineer crops for resistance to specific ACCase inhibitors and synthetic auxins that will still be effective in controlling weeds associated with future HR crops.

If crops that are resistant to multiple herbicides—including ALS inhibitors, ACCase inhibitors, synthetic auxins, and glyphosate—are widely planted, continued use of the herbicides in fields that contain weeds already resistant to some of them could involve a risk of selecting for high levels of multiple herbicide resistance. The ability of weeds to evolve biotypes that have multiple herbicide resistance has already been demonstrated in waterhemp populations in Illinois and Missouri that are resistant to three herbicide mechanisms of action (Patzoldt et al., 2005; Legleiter and Bradley, 2008). Evolved multiple resistance will exacerbate problems of controlling some key herbicide-resistant weeds, and local and regional spatially explicit information on the distribution of weeds that are resistant to glyphosate and other herbicides

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could be useful in helping to manage such a situation (Werth et al., 2008). Tank-mixes and sequencing herbicides rely on redundancy to be effective. Models assessing sequential use of herbicides only, or of herbicides and mechanical weed control, indicate that a low frequency of alleles conferring resistance to herbicides and high weed mortality are critical factors for these strategies to substantially delay the evolution of weed resistant to glyphosate in HR crops (Neve et al., 2003; Neve, 2008; Werth et al., 2008).

In conclusion, regardless of the specific herbicide for which HR crops are genetically engineered, only appropriate stewardship by the grower will delay the evolution of resistance to the herbicide. Resistance management is voluntary in the United States for all pesticides except Bt produced by Bt crops (Berwald et al., 2006; Thompson et al., 2008). Given the rapid increase in and expansion of weeds that are resistant to glyphosate in HR crops, herbicide-resistance management needs national attention. As discussed previously, the rapid evolution of weed resistance to glyphosate has probably been a consequence of growers' management decisions that favored the use of glyphosate as the primary, if not sole, tactic to control weeds despite efforts in the private and public sectors to strongly recommend alternative strategies (Johnson et al., 2009). Without changes in production practices, the increase in weeds resistant to glyphosate will likely increase weed-management expenses for farmers. The evolution of herbicide resistance and other weed shifts associated with the adoption of GE crops requires the development and use of more effective weed-management strategies and tactics (Beckie, 2006; Murphy and Lemerle, 2006; Green et al., 2008; Gustafson, 2008; Powles, 2008; Werth et al., 2008).

Diversification of weed-management strategies can be accomplished by integrating several weed-control tactics: herbicide rotation, herbicide application sequences, and the use of tank-mixes of more than one herbicide; the use of herbicides that have different modes of action, methods of application, and persistence; cultural and mechanical control practices; and equipment-cleaning and harvesting practices that minimize the dispersal of herbicide-resistant weeds. Although the strategies to mitigate weed shifts are readily identified, they have largely been ignored because of the scale of commercial agriculture, which favors the simplicity, convenience, and short-term success of herbicide use over more time-consuming strategies that can be burdensome to implement on farms (Shaner, 2000; Mueller et al., 2005; Johnson and Gibson, 2006; Sammons et al., 2007; Owen, 2008). Furthermore, increased reliance on glyphosate for weed control in glyphosate-resistant crops has reduced the price of other herbicides in the United States and has limited efforts to develop new herbicides (Shaner, 2000; Duke, 2005). Companies are increasingly focused on expanding the use of currently registered herbicides, which can be achieved by commercializing GE crops that are resistant to more than one herbicide (Duke, 2005; Green, 2007, 2009). Delaying the evolution of resistance to herbicides that are used with HR crops and minimizing other weed shifts are particularly important in this context because new herbicides may not be readily available to replace ones that become ineffective when resistance evolves. Therefore, farmers would benefit from focusing on more diverse, longer-term weed-management strategies to preserve the effectiveness of HR crops and to minimize the possibility of more expensive control tactics in the future.

ENVIRONMENTAL IMPACTS OF INSECT-RESISTANT CROPS

The adoption of Bt crops has changed insect-management strategies for most corn and cotton farmers in the United States. Those changes have implications for pest populations, soil

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conditions, and the management of insect pests in the future. The following section evaluates the impact of insect-resistant (IR) crop adoption on pest populations, on nontarget insects, and on soil quality. It also investigates resistance-management strategies and concerns related to the continued effectiveness of IR crops.

Levels of Insecticide Use

Insecticide Use in Corn

Insecticide use in corn (in pounds per acre) has steadily declined since 1997 as the adoption of Bt corn (which reached 50 percent of corn acres planted in 2007) has increased (Figure 2-7). Bt corn was introduced in the mid-1990s to control the European corn borer (*Ostrinia nubilalis*). Because chemical control of the European corn borer was not always profitable (and timely application was difficult) before the introduction of Bt corn, many farmers accepted yield losses rather than incur the expense and uncertainty of chemical control. For those farmers, the introduction of Bt corn resulted in yield gains rather than pesticide savings (Fernandez-Cornejo and Caswell, 2006). However, a new type of Bt corn introduced in 2003 to protect against corn rootworm (*Diabrotica* spp.), which was previously controlled with chemical insecticides and crop rotation, has provided substantial insecticide savings (Fernandez-Cornejo and Caswell, 2006).

Insecticide Use in Cotton

Cotton has the highest traditional use of insecticides per acre and the highest rate of adoption of Bt crops, reaching almost 60 percent in 2007, 12 years after Bt cotton was first commercialized (Figure 2-8). Insecticide use has fallen (in pounds per acre) over the same period, but fluctuations in total cotton insecticide applications have also been strongly affected by the boll weevil eradication program[8] (Fernandez-Cornejo et al., 2009).

[8]Since the 1970s, cotton growers and governments have worked toward eradicating the boll weevil, a beetle that affects cotton and that is not directly affected by Bt cotton. Different cotton-growing regions joined the program in different years. Typically, the first year of participation entails heavy application of pesticides (generally malathion). In subsequent years, the boll weevil population is monitored and treated as needed. A new wave of cotton-growing regions began participating in 1993. The spike in cotton insecticide applications in 1999 and 2000 coincides with the entry of 2 million cotton acres into the program in Texas (Fernandez-Cornejo et al., 2009).

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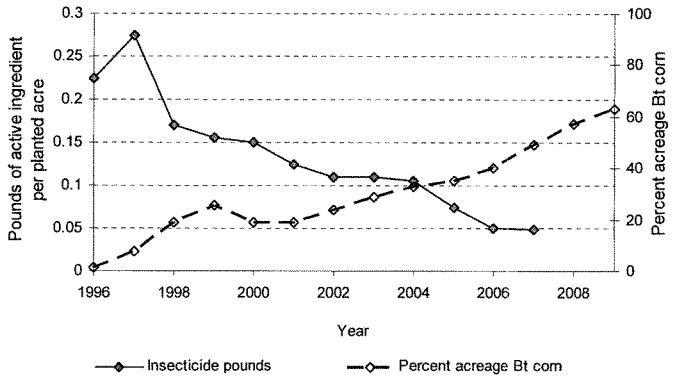


FIGURE 2-7 Pounds of insecticide applied per planted acre and percentage of acres of Bt corn, respectively.
NOTE: Seed-applied insecticide not included. Furthermore, the strong correlation between the rising percentage of Bt corn acres planted over time and the decrease in insecticide pounds per planted acre suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

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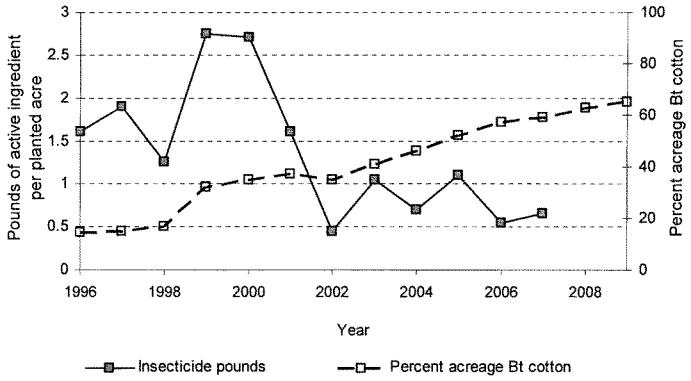


FIGURE 2-8 Pounds of insecticide applied per planted acre and percentage of acres of Bt cotton, respectively.
NOTE: The strong correlation between the rising percentage of Bt cotton acres planted over time and the decrease in insecticide pounds per planted acre suggests but does not confirm causation between these variables.
SOURCES: USDA-NASS, 2001; 2003, 2005, 2007, 2009a, b; Fernandez-Cornejo et al., 2009.

Regional Pest Reductions

Corn and cotton that produce Bt toxins can cause high mortality in insect pest populations in which Bt-resistance alleles are rare. For example, mortality in pink bollworm (*Pectinophora gossypiella*) and tobacco budworm (*Heliothis virescens*) on Cry1Ac cotton is virtually 100 percent throughout the growing season (Tabashnik et al., 2000; Showalter et al., 2009) . However, mortality in the moths *Helicoverpa armigera* and *Helicoverpa zea*[9] on Cry1Ac cotton is typically lower than 95 percent and declines during the growing season (Kennedy and Storer, 2000; Olsen et al., 2005; Tabashnik et al., 2008; Showalter et al., 2009). Crops that produce more than one Bt toxin generally cause higher mortality than crops that produce a single toxin although declines in mortality during the growing season may still be observed (Adamczyk et al., 2001; Bommireddy and Leonard, 2008; Mahon and Olsen, 2009; Showalter et al., 2009).

Because Bt crops can cause high pest mortality, it has been postulated that one effect of the widespread use of Bt crops is a reduction in some pest populations regionally (Kennedy et al., 1987; Alstad and Andow, 1995; Roush, 1997; Gould, 1998; Kennedy and Storer, 2000; Storer et

[9] *Helicoverpa armigera* and *Helicoverpa zea* are known by many common names, depending on the host plant. *Helicoverpa armigera* is referred to as old world bollworm or cotton bollworm (when it feeds on cotton), pod borer (when it feeds on chickpea or pigeon pea), tomato fruit borer (when it feeds on tomato), and corn earworm (when it feeds on corn). *Helicoverpa zea* is often called cotton bollworm, corn earworm, or tomato fruitworm.

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al., 2003). According to that idea, an area-wide decline in pest abundance could occur because replacing non-Bt crop fields with Bt crop fields eliminates suitable habitats for the pests. If females lay eggs on Bt plants and on non-Bt host plants, laying eggs on Bt plants could substantially reduce the number of surviving offspring produced by females and cause a decline in pest density (Riggin-Bucci and Gould, 1997; Carrière et al., 2003; Shelton et al., 2008). Models have suggested that the suppression of pest populations is more likely as mortality induced by Bt crops increases, the abundance of Bt crops and female movement between patches of Bt and non-Bt plants increase, and the net reproductive rate in patches of non-Bt hosts decreases (Carrière et al., 2003). However, polyphagous pest species (those able to feed on multiple types of plants) often exploit crops sequentially during the growing season, tracking changes in host suitability (Kennedy and Storer, 2000). In some cropping systems, the feeding options of such pests might be limited to only a Bt crop for a few generations, when it is the only suitable resource available. Thus, Bt crops could affect pest population dynamics even when the crops are relatively rare (Kennedy et al., 1987; Wu et al., 2008).

Long-term monitoring of insect-pest density before and after commercialization of Bt crops has provided evidence that deployment of Bt crops influences pest population dynamics regionally. Table 2 3 contains the results of pest-monitoring studies in the United States and China. Most of the studies covered a single region where spatially explicit data on the distribution of Bt crops were not available, but in one study of pink bollworm population density in Arizona from 5 years before to 5 years after introduction of Bt cotton, the abundance of Bt and non-Bt cotton fields in 15 cotton-growing regions was quantified with geographical information system technology (Carrière et al., 2003). In regions with less than an average of 65 percent Bt cotton in the second 5-year period, the introduction of Bt cotton had no consistent effect on population density of pink bollworm; in regions with more than 65 percent Bt cotton, the introduction of Bt cotton decreased pink bollworm population density, and the extent of the decline increased as the percentage of Bt cotton increased. Those data are consistent with modeling results and suggest that pest-population suppression occurs if the area of Bt crops exceeds a threshold percentage of Bt cotton (Carrière et al., 2003). Another recent study of the European corn borer conducted in five major U.S. corn-producing states indicated that suppressive effects of Bt corn depended on the extent of adoption of the technology (Hutchison et al., 2007).

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TABLE 2-3 Regional Effects of Deployment of Bt Crops on Population Dynamics of Major Pests of Corn and Cotton

Pest	Location	Regional Use of Bt Crops	Number of Years Monitored	Population Decline	Reference
Heliothis virescens	Mississippi (Washington County)	Up to 85% Bt cotton	19 (1986–2005)	Yes	Adamczyk Jr. et al., 2001
Helicoverpa zea	Mississippi (Washington County)	Up to 85% Bt cotton	19 (1986–2005)	Yes	Adamczyk Jr. et al., 2001
Heliothis virescens	Louisiana (Bossier City)	Unknown	20 (1986–2005)	Yes	Micinski et al., 2008
Helicoverpa zea	Louisiana (Bossier City)	Unknown	20 (1986–2005)	No	Micinski et al., 2008
Ostrinia nubilalis	Maryland (Eastern Shore)	Up to 60% Bt corn	35 (1973–2007)	Yes	Storer et al., 2008
Helicoverpa zea	Maryland (Eastern Shore)	Up to 60% Bt corn	35 (1973–2007)	Yes	Storer et al., 2008
Helicoverpa armigera	China (Six provinces)	Up to 10% Bt cotton	10 (1997–2006)	Yes[a]	Wu et al., 2008
Ostrinia nubilalis	Minnesota, Illinois, Iowa, Nebraska, Wisconsin	Up to 75% Bt corn	ca. 45 years (1943–2007)[b]	Yes	Hutchison et al., 2007
Pectinophora gossypiella	Arizona (15 regions)	0.01–87% Bt cotton	10 (1992–2001)	Yes	Carrière et al., 2003

[a]Study analyzed decline in density of *H. armigera* after commercialization of Bt cotton.
[b]Data analyzed for about 45 years in each state. Not all states were monitored each year in the period 1943–2007.

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Storer et al. (2008) noted that producers, extension agents, and pesticide appliers reported less serious insect-pest control problems in non-Bt crops, such as soybean and vegetables, after the regional suppression of the European corn borer and the corn earworm (*H. zea*) by Bt corn in Maryland. As a comparison to the U.S. experience, a study conducted in six provinces of China from 1997 to 2006 documented a progressive decline in the population density of cotton bollworm (*H. armigera*) after the introduction of Bt cotton (Wu et al., 2008) (Table 2-3). The significant suppression of cotton bollworm occurred not only in Bt and non-Bt cotton but in corn, peanut, soybean, and vegetables. Wu et al. (2008) proposed that the regional decline of cotton bollworm populations could reduce insecticide use in crops other than cotton. Nevertheless, the economic consequences of the regional suppression of pests by Bt crops have been investigated only for European corn borer in five U.S. Corn Belt states (Hutchison et al., 2007). It was estimated that regional declines in European corn borer population densities during the last 14 years in those states saved at least $3.9 billion for producers of non-Bt corn and $6.1 billion for producers of Bt and non-Bt corn combined. Further detailed spatially explicit studies of the association between the distribution of Bt crops and pest problems on different scales will be helpful in improving understanding of how the use of Bt crops can reduce pest abundances (Marvier et al., 2008).

The use of Bt crops sometimes changes pest-management practices enough to increase problems related to pests that are not killed by Bt toxins. For example, substantial reductions in the use of synthetic insecticides on Bt cotton favored outbreaks of mirids and leafhoppers in China (Wu et al., 2002; Men et al., 2005). Those pests had been well controlled by insecticides before the introduction of Bt cotton. Similarly, lower use of insecticides in Bt cotton probably contributed to the higher stink bug damage in cotton in some southern U.S. states although the regional increases in stink bug populations were probably influenced by other factors as well (Greene et al., 2001; Greene et al., 2006). Changes in pest-management practices in connection with Bt crops can also have favorable consequences for the control of some pests that are not killed by Bt toxins. For example, a reduction in insecticide use on Bt cotton was sometimes associated with greater predator abundance and better pest control in cotton aphid in the United States (see section "Natural Enemies").

Reversal of Insect Resistance to Synthetic Insecticides

The deployment of Bt crops is known to promote a reversal of pest resistance to synthetic insecticides, but this has not yet been observed in United States. In northern China, the reduction in use of insecticides on Bt cotton contributed to restoring cotton bollworm (*H. armigera*) susceptibility to some synthetic insecticides (Wu et al., 2005; Wu, 2007) although fitness costs associated with insecticide resistance likely helped to increase susceptibility. Similarly, resistance to pyrethroid insecticides declined considerably in tobacco budworm (*H. virescens*) after the introduction of Bt cotton in southern Tamaulipas, Mexico (Terán-Vargas et al., 2005). The renewed efficacy of insecticides provided more pest-management options to producers in those regions. However, such reversals in insecticide resistance do not always occur. For example, the planting of Bt cotton in Louisiana did not change the high levels of pyrethroid resistance in tobacco budworm (*H. virescens*) and cotton bollworm (*H. zea*) (Bagwell et al., 2001), and *H. zea* resistance to pyrethroids increased substantially after the planting of Bt cotton in several regions of Texas (Pietrantonio et al., 2007).

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Effects on Nontarget Species

Bt toxins are considered acutely toxic to a relatively narrow array of invertebrate taxa when compared with broad-spectrum insecticides because toxicity through direct ingestion of a Bt toxin is typically restricted to insects in the same order as the target pest (Schnepf et al., 1998; Glare and O'Callaghan, 2000; van Frankenhuyzen and Nystrom, 2002; Mendelsohn et al., 2003). For example, the endotoxins Cry1Aa, Cry1Ab, and Cry1Ac kill mainly particular moths and butterfly species, while Cry3Aa and Cry3Bb mainly kill particular beetle species. Furthermore, because Bt toxins are specific, they cause different mortality within targeted insect orders. For example, the cotton cultivar Bollgard I®, which produces the toxin Cry1Ac and targets lepidopteran pests, kills virtually 100 percent of pink bollworm and tobacco budworm (*H. virescens*), between 24–95 percent of cotton bollworms *H. zea* and *H. armigera*, and less than 4 percent of fall armyworm (*Spodoptera frugiperda*) and beet armyworm (*Spodoptera exigua*) (Showalter et al., 2009). Field studies have revealed relatively few adverse effects of Bt crops on arthropods that are not closely related to the target pests (Cattaneo et al., 2006; Romeis et al., 2006). In contrast, broad-spectrum insecticides, such as pyrethroids and organophosphates had consistent, adverse effects on a wide array of nontarget arthropods (Cattaneo et al., 2006; Romeis et al., 2006).

Although the high specificity of Bt crops for the control of target pests is consistent with integrated pest management, they may have effects on beneficial organisms. For example, the larvae of nontarget moths or butterflies in the landscape surrounding farms may be susceptible to Bt toxins that target pests in this group, but they would need to eat the Bt plant material to be affected. Bt corn byproducts that enter streams may affect aquatic insects in related taxa (Rosi-Marshall et al., 2007). The abundance of some natural enemies may decrease when their host or prey species are susceptible to Bt toxins and as a result become rare or nutritionally less suitable (Romeis et al., 2006).

Quantifying and predicting the effects of Bt crops on nontarget invertebrate species has been the subject of considerable work. As compiled by Marvier et al. (2007) and Naranjo (2009), research on the nontarget effects of Bt crops includes 135 laboratory studies of nine Bt crops and 22 Bt Cry proteins or protein combinations and 63 field studies of five Bt crops and 13 Bt proteins. In total, field and laboratory studies of at least 99 and 185 invertebrate species, respectively, have been conducted although not with equal effort. Most of the field studies have been of corn and cotton. Individual study results vary, so evidence-based generalizations are elusive in the absence of formal approaches. A review of recent syntheses provides an overview of the generalizations that have emerged thus far from those efforts.

For cotton and corn, whether Bt crop fields have more or fewer nontarget invertebrates depends on whether one compares the Bt crop to a conventional counterpart that received insecticide treatments (Marvier et al., 2007; Wolfenbarger et al., 2008; Naranjo, 2009). Collectively, studies have indicated that a higher total abundance of arthropods occurred in Bt fields than in conventional fields sprayed with insecticides and a lower abundance than in conventional fields with no insecticide treatment (Marvier et al., 2007). For Bt corn, the magnitude of the effect also depended on whether studies tested Bt176 (no longer registered for use) or the MON810 (commercially used) Bt events. Lower abundance of specific taxa was found in Bt fields than in unsprayed, non-Bt fields; the taxa in question included moths, butterflies, beetles, and true bugs on cotton and wasps on corn. Differences in the availability of prey or in survival may explain those results (Marvier et al., 2007).

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Bt potato crop fields without insecticide use contained higher abundances of predators, natural enemies as a whole, and nontarget pests compared to conventional potato fields, whether or not insecticides were applied to the conventional fields (Wolfenbarger et al., 2008).

Natural Enemies

Maintenance of healthy populations of predators of crop pests is a desirable goal for ensuring long-term environmental sustainability of farms. Decreasing the numbers of predators, which in practice will be related to the overall biodiversity in an area and to on-farm pest control (Landis et al., 2008), would be undesirable. Even in systems where a single predator may suffice as a biocontrol agent, redundancy is an important tool for ensuring ecosystem services.

The few studies comparing biological control (by parasitism and predation rates) between Bt and conventional crops have suggested that control of nontarget pests on Bt crops was enhanced on cotton (Head et al., 2005) or similar on cotton (Naranjo, 2005) and corn (Pons and Starý, 2003; Naranjo, 2005) and that control of target pests on Bt crops was enhanced on cotton (Head et al., 2005), similar on cotton (Sisterson et al., 2004b; Naranjo, 2005) and corn (Orr and Landis, 1997; Sisterson et al., 2004b; Naranjo, 2005), or reduced on corn (Siegfried et al., 2001; Bourguet et al., 2002; Manachini, 2003; cited by Naranjo, 2009). Maintenance of biological control of nontarget pests in one study occurred in Bt cotton fields in spite of about a 20 percent reduction in the abundance of some common predators (Naranjo, 2005). When Bt crops have completely replaced insecticide-treated conventional crops, studies have consistently reported higher numbers of predators on cotton, corn, and potato. When Bt crops have replaced non-insecticide-treated conventional crops, results studies have consistently indicated slightly fewer predators on Bt cotton and no detectable difference on Bt corn (Wolfenbarger et al., 2008; Naranjo, 2009).

Field studies of parasitoids have overemphasized specialist species of the target pest of Bt corn, so generalizations to parasitoids as a group are premature. The studies have revealed a pattern similar to that of predators: fewer parasitoids in conventional corn fields sprayed with insecticides and no detectable difference between Bt corn fields and conventional corn fields not treated with insecticides. Laboratory studies indicate that effects of Bt toxins on parasitoids depend on whether they are fed prey that are susceptible to Bt toxins (Zwahlen et al., 2000; Dutton et al., 2002; Schuler et al., 2003; Schuler et al., 2004; Romeis et al., 2006). Syntheses of laboratory studies of 14 parasitoid species indicate a favorable or neutral effect on life-history traits when they were fed prey that had ingested a Bt toxin but were not affected by it (high-quality prey). Conversely, studies have shown longer development times, lower reproduction, and lower survival if the parasitoids were fed prey that had ingested a Bt toxin that was toxic to them (low-quality prey) (Naranjo, 2009).

The adoption of Bt cotton increases abundances of natural enemies and hence the potential for biological control when it completely replaces insecticide treatments. Moth larvae were responsible for a large fraction of cotton insect losses before the adoption of Bt cotton, but cotton-insect losses caused by these larvae have become less important now that Bt cotton has been widely adopted. The five major insect pests of cotton in the United States in 2008 were lygus bugs (1 percent yield loss), bollworms and budworms (0.76 percent yield loss), stink bugs (0.75 percent yield loss), thrips (0.52 percent yield loss), and cotton fleahoppers (0.23 percent yield loss) (Williams, 2008). Among those, only bollworms and budworms are controlled by Bt cotton, so the use of Bt cotton rarely eliminates all insecticide applications. Actual farm-level

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reductions in insecticide use for Bt cotton would probably increase the abundance of nontarget insects less consistently (e.g., Cattaneo et al., 2006; Sisterson et al., 2007) than what has been observed in experimental studies in which the use of Bt cotton completely replaced insecticide treatments.

Pollinators and Other Valued Insects

The honey bee (*Apis mellifera*) is one of the agricultural sector's most important pollinators. Laboratory toxicity studies of honey bees have consistently found no evidence that Bt pollen or Bt proteins decrease honey-bee larval or adult survival (Duan et al., 2008) even at toxin concentrations well beyond what would be encountered in the field. There have been laboratory or field studies of few other species (Wolfenbarger et al., 2008; Naranjo, 2009); no consistent effect on development time (eight studies) or survival (20 studies) has been detected in laboratory tests, but effects varied widely among studies, particularly for development time (Naranjo, 2009). Laboratory studies collectively have indicated longer development time and lower survival of valued insect herbivores, a category that includes charismatic species (e.g., monarch butterfly larvae), and moths of economic importance (e.g., the silkworm) (Naranjo, 2009).

Summary of Nontarget Effects

The abundance of natural enemies on Bt crops can be greater than, the same, or lower than on non-Bt crops. The magnitude of the benefit depends on the extent to which a Bt crop substitutes for the use of insecticide treatments of non-Bt crops and on whether insecticides for other pests are used on the Bt crop. Honey-bee adults and larvae were not harmed by Bt pollen or Bt proteins, but too few pollinators have been studied to support generalizations about the group as a whole. As the sophistication of GE-crop varieties increases and the functional roles of arthropods become understood more fully, it should be possible to develop strategic pest-management systems that maintain high crop productivity while avoiding effects on nontarget moths, butterflies, and beetles.

Soil Quality

Overall, it appears that current Bt crops have no greater or less effect on soil quality than the crops that they have replaced. Many peer-reviewed studies have addressed the nontarget impacts of Bt crops on soil organisms. Specifically, studies have considered the effects of plant residues on the soil community because plants are the primary source of carbon in soils. If Bt toxins affect soil microorganisms, rates of decomposition and nutrient cycling may be altered. Studies have also focused on the consequences of Bt-containing root exudate. Root exudate influences the soil community, especially the community of distinct, specialized soil microorganisms associated with roots.

Most assessments of the effects of Bt insecticidal proteins on soil microorganisms and other organisms have found that these proteins do not substantially alter microbial populations and measured functions (Icoz and Stotzky, 2008). Over four years of continuous corn cultivation, Bt plant residues and root exudates had no consistent or persistent effect on a breadth of

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microorganisms or their enzymatic activity in the soil, but differences were detected according to plant species, variety, and age as well as other environmental factors (Icoz et al., 2008). With respect to macroorganisms, Lang et al. (2006) found no significant differences in earthworm or springtail population density or biomass between soils with Bt and with non-Bt corn or between soils with corn treated and not treated with insecticide (baythroids) at five sites during 4 years of corn cultivation. Instead, the site and the sampling years had a greater influence on earthworm population density and biomass than the presence of the Cry protein. Those results corroborate other laboratory and field studies of the effect of Bt toxins on survival, growth, and reproduction of an array of soil invertebrates, including woodlice, springtails, and mites (Ahl Goy et al., 1995; Saxena and Stotzky, 2001a; Zwahlen et al., 2003; Clark et al., 2006; Vercesi et al., 2006; Krogh et al., 2007). Similarly, Birch et al. (2007) detected transient and site-specific reductions in the biomass of oribatid mites and total microarthropods in fields under Bt and non-Bt corn. However, the differences between populations under different non-Bt corn varieties were often of the same magnitude as those between Bt and non-Bt corn; this led to the conclusion that the effects in the field were varietal effects and not due specifically to the Bt trait (Cortet et al., 2006).

When the effects of Bt toxins on nematodes were studied, season, soil tillage, soil type, crop type, and cultivar influenced nematode number to a greater extent than whether the corn was a Bt variety. Under field cultivation for Bt-crops with the Cry3Bb1 protein and non-Bt crops, no effect was detected on the abundance of the nematode *Caenorhabditis elegans* on corn (Al-Deeb et al., 2003, corn) or on the relative abundance of species of nematodes in the soil with eggplant (Manachini, 2003; eggplant, cited by Icoz and Stotzky, 2008). When soils from Bt corn with the Cry1Ab protein and non-Bt corn in cultivation were compared, there were no effects on nematode communities and diversity (Manachini, 2003; cited by Icoz and Stotzky, 2008) or on the nematode *Pratylenchus* spp. (Lang et al., 2006). However, in experiments in cultivated Bt and non-Bt corn fields, adverse effects on growth and abundance of *C. elegans* were observed (Manachini, 2003; Lang et al., 2006; cited by Icoz and Stotzky, 2008), and a lower abundance of natural populations occurred transiently in Bt fields and consistently at one Bt site (Griffiths et al., 2005; Griffiths et al., 2006).

Similarly, the Cry1Ab insecticidal protein for European corn borer control had less effect on the bacterial community structure than other environmental factors (Baumgarte and Tebbe, 2005). In one study, a transient decrease occurred in the numbers of protozoa in soil with Bt corn under field conditions (Griffiths et al., 2005); otherwise, no toxic effects of the Cry proteins on protozoa have been observed (Donegan et al., 1995; Saxena and Stotzky, 2001a; Griffiths et al., 2005; Icoz and Stotzky, 2008). No changes in microbial activity and other assays (i.e., nitrogen mineralization potential, short-term nitrification, and soil respiration rate) occurred when soils cropped with corn that produced the Cry3Bb toxin for corn rootworm protection were compared with soils cropped with the nontransgenic isoline (Devare et al., 2004; Devare et al., 2007). Those studies have indicated that Bt and non-Bt crops have comparable effects on soil bacteria and protozoa.

Rates of residue decomposition and the associated accumulation of soil organic matter affect soil productivity and soil ecological functions; therefore, if residues of Bt corn differ from residues of non-Bt corn in decomposition rates, there might be long-term implications for soil quality and soil carbon sequestration. Reduced decomposition rates might increase the time that Bt toxins remain in the environment. Chemical bonds in lignins are more resistant to microbial decomposition than other chemical bonds in plant cells. Some studies have demonstrated higher

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lignin content in Bt corn hybrids compared to their respective isolines (or near-isolines) (Saxena and Stotzky, 2001b; Poerschmann et al., 2005), but other studies have found no differences (Jung and Sheaffer, 2004). Decomposition rates have more importance for soil quality than relative lignin contact. In some laboratory research, plant residue of Bt hybrids decomposed at a lower rate in soil than residue of non-Bt hybrids (Flores et al., 2005), but field studies have not detected differences in decomposition rates (Lehman et al., 2008). Similarly, Hopkins and Gregorich (2003) reported no differences in carbon dioxide production from Bt and non-Bt corn in soil over a 43-day incubation period. No differences in mass losses in the field were detected between Bt-glyphosate–resistant and glyphosate-resistant cotton lines, indicating that there were no differences in the rate of decomposition or change in nutrient content in the litter over the 20-week experiment (Lachnicht et al., 2004). When the whole soil organism community was allowed to access the residue, the decomposition of Bt and non-Bt residue was similar (Zwahlen et al., 2007). Tarkalson et al. (2008) also reported no differences in residue decomposition rates or in mass of total carbon remaining over time between Bt and non-Bt corn hybrids observed in a field study although the study did detect differences in rates of decomposition for leaf, stalk, and cob plant parts. Finally, after seven years of continuous corn cultivation, no differences between Bt and non-Bt corn treatments were detected in total carbon or nitrogen in soil, indicating that plant decomposition rates were similar (Kravchenko et al., 2009). On the basis of those studies, the plant residue from Bt and non-Bt corn hybrids decomposed at similar rates and would have similar effects on soil quality and on potential carbon sequestration.

Evolution and Management of Insect Resistance

Evolution of Resistance

Insects can adapt to toxins and other tactics used to control them (Palumbi, 2001; Onstad, 2008). When Bt crops were first considered for commercial introduction, EPA recognized their potential to reduce human and environmental exposure to broad-spectrum insecticides, increase growers' ability to manage pests and improve crop quality, and increase profits at the farm and industry levels (Berwald et al., 2006; Matten et al., 2008). Those benefits had already been demonstrated by sprayed Bt insecticides that are critical pest-management tools for many fruit and vegetable crops in the United States (K. Walker et al., 2003). As the regulatory agency overseeing the introduction of biological pesticides, EPA concluded that the potential for rapid evolution of insect resistance to Bt toxins produced by GE crops was a threat to the benefits provided by Bt crops and to the efficacy of Bt sprays in organic and conventional production systems (Matten et al., 2008; Thompson et al., 2008). Accordingly, it mandated the use of a refuge strategy (described later in this chapter) to delay the evolution of resistance in major insect pests controlled by Bt corn and cotton (US-EPA, 2008a).

Extensive monitoring of 11 major lepidopteran pests of corn and cotton over the last 14 years has revealed that some populations of one moth species, cotton bollworm (*Helicoverpa zea*), evolved resistance to the Bt toxins Cry1Ac and Cry2Ab found in some cotton cultivars in the United States (Tabashnik and Carrière, 2008; Tabashnik et al., 2008; Tabashnik et al., 2009a). In addition, some populations of fall armyworm evolved resistance to Cry1F corn in Puerto Rico (Matten et al., 2008), and some populations of corn stem borer (*Busseola fusca*) evolved resistance to Cry1Ab corn in South Africa (van Rensburg, 2007; Kruger et al., 2009).

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That resistance has evolved in only three pest species in the last 14 years suggests that the refuge strategy has successfully delayed the evolution of resistance to Bt toxins (Tabashnik et al., 2008; Tabashnik et al., 2009a). Comparisons between pests that have and have not evolved resistance to Bt crops suggest that recessive inheritance of resistance and abundant refuges of non-Bt host plants are two key factors that delay the evolution of resistance (Tabashnik et al., 2008; Tabashnik et al., 2009a). In accordance with these findings, EPA demands that GE seed companies require producers to plant refuges to delay the evolution of resistance where such refuges are deemed necessary and develop compliance assurance programs (Thompson et al., 2008). The promotion of precise resistance-management guidelines by the industry has undoubtedly contributed to increasing the use of refuges for managing the evolution of resistance to Bt crops in the United States. In some regions, compliance to the mandated refuge strategies has been high since the introduction of Bt crops (Carrière et al., 2005). However, levels of compliance have substantially and regularly declined in other parts of the country, possibly because the use of Bt crops has increased globally and producers can no longer rely on non-Bt users to provide refuges for their farms (Jaffe, 2009).

Although the theory, resistance-monitoring data, and experimental work conducted in the laboratory suggest the refuge strategy has been useful, detailed field experiments are still needed to demonstrate how the refuge strategy can delay the evolution of resistance to Bt crops. There is usually a delay between the introduction of a novel pesticide and the rapid rise in the number of species that have evolved resistance to it (Georghiou, 1986). That is illustrated in a comparison of the cumulative number of cotton pests that evolved resistance to Bt toxins in crops and to the insecticide dichlorodiphenyltrichloroethane (DDT) after the introduction of these pest-management tools in the United States (Figure 2-9).

After commercialization of Bt cotton in 1996, its use increased rapidly in the United States. Similarly, the use of DDT in cotton increased rapidly after it became widely commercially available in 1946. For example, 90 percent of agricultural DDT applications in the United States targeted cotton pests in 1962 (Walker et al., 2003). Similar to Bt cotton that produces high concentrations of Bt toxins over much of the growing season, DDT was applied repeatedly in cotton and retained toxicity for extended periods (US-EPA, 2000). The recessive mutations *kdr* and super-*kdr* confer recessive resistance to DDT in many agricultural pests (Davies et al., 2007; APRD, 2009); this is similar to the inheritance of resistance to Bt toxins in cotton, which is often recessive (Tabashnik et al., 2008).

With respect to the evolution of resistance, Bt cotton and DDT differ in at least two important ways. First, DDT kills a wide array of insects regardless of their feeding habits whereas Bt cotton kills only some lepidopteran pests that feed on the cotton. Second, no refuge strategy was mandated to manage the evolution of insect resistance to DDT. Those differences suggest that the evolution of DDT resistance in cotton pests should have been more rapid than the evolution of resistance to Bt cotton. However, the cumulative number of cotton pests that evolved resistance to Bt cotton and the number that evolved resistance to DDT after their introduction in the United States have been strikingly similar (Figure 2-9). That comparison indicates that it may still be too soon to claim that the refuge strategy has substantially delayed the accumulation of pests resistant to Bt. While seed companies are in a better position to commercialize more efficient Bt cultivars for delaying the evolution of resistance (see below), the possibility remains that the accumulation of resistant pests could accelerate. Thus, complacency in the implementation of resistance-management strategies is not warranted (Hurley and Mitchell, 2008; Jaffe, 2009; Tabashnik et al., 2009a).

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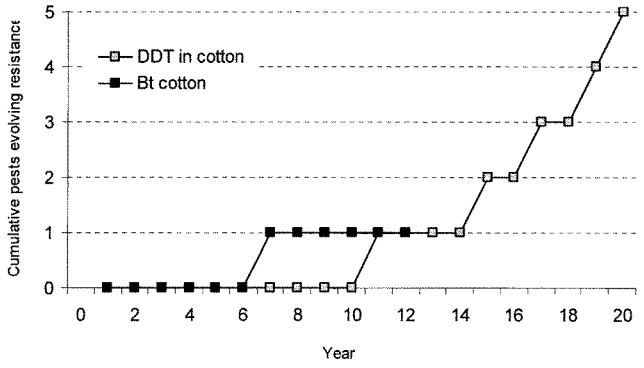


FIGURE 2-9 Cumulative number of cotton pests evolving resistance to Bt cotton and DDT in the years after these management tools became widely used in the United States.
SOURCE: APRD, 2009.

Principles of Population Genetics Underlying the Refuge Strategy

Population-genetic models and empirical data on factors that affect the evolution of insect resistance to Bt crops have been central in the development of the refuge strategy. Models generally assume that resistance to a toxin produced by Bt crops is conferred by mutations at a single locus (gene location) (Gould, 1998; Tabashnik and Carrière, 2008). That is a reasonable assumption because resistance to the intense selection imposed by Bt crops and insecticides is likely to involve genes that have major effects (Carrière and Roff, 1995; McKenzie, 1996). Furthermore, most of the observed cases of evolved resistance to Bt crops have involved mutations at a single locus (Gahan et al., 2001; Morin et al., 2003; Yang et al., 2007; Pereira et al., 2008). For simplicity, models assume the presence of one allele that confers susceptibility and one allele that confers resistance even if more than one allele at a single locus can confer resistance to Bt crops (Morin et al., 2003; Yang et al., 2007).

The refuge strategy relies on two basic principles. The first principle is that the dominance of resistance[10] is reduced by increasing the dose of Bt toxins (Gould, 1998; Tabashnik et al., 2004). When the concentration of a Bt toxin in a plant is low, the resistance trait in the insect population is nonrecessive, but when it is high, the resistance trait in the insect population becomes recessive, and resistance becomes rarer. Accordingly, resistance to commercialized GE crops

[10]The *dominance of resistance* depends on the response of heterozygotes compared to the response of homozygous-susceptible individuals and homozygous-resistant individuals. If heterozygotes respond like homozygous-susceptible individuals, resistance is recessive; if heterozygotes respond like homozygous-resistant individuals, resistance is dominant.

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that produce high concentrations of Bt toxins is recessive in many, but not all, target pests (Tabashnik et al., 2008). The refuge strategy requires the presence of refuges of non-GE host plants in or near Bt crop fields (US-EPA, 2008b, a). For refuges to be effective, the susceptible insects produced in refuges must be in sufficient numbers and mate with the rare resistant pests that survive on GE crops. With effective refuges and recessive resistance, most hybrid offspring produced by resistant pests that survive on Bt crops are killed when they feed on GE crops. That reduces the heritability of resistance (the degree of genetic similarity between resistant parents that survive on Bt crops and their offspring) and delays its evolution (Gould, 1998; Sisterson et al., 2004a; Tabashnik and Carrière, 2008).

The second principle underlying the refuge strategy is that the evolution of resistance can be delayed or prevented by reducing the selective differential between individuals with and without resistance alleles (Gould, 1998; Carrière and Tabashnik, 2001; Andow and Ives, 2002; Tabashnik et al., 2005; Crowder and Carrière, 2009). The selective differential between resistant and susceptible individuals can be affected by crop-management practices, such as increasing refuge size that increases relative fitness of susceptible individuals (Mitchell and Onstad, 2005; Onstad, 2008). In fields of Bt crops, where resistant individuals are more abundant than susceptible individuals, the selective differential between resistant and susceptible individuals can be reduced by such crop-management practices as pheromone mating disruption and the elimination of crop residues that contain insects (Andow and Ives, 2002; Yves Carrière et al., 2004).

The selective differential between resistant and susceptible individuals can also be affected by pest biology and genetics. Fitness costs associated with resistance to Bt toxins occur in environments that lack Bt toxins if individuals with one or more resistance alleles have lower fitness than individuals without such alleles (Gassmann et al., 2009). Fitness costs of Bt resistance are found in many species and select against resistance in environments where Bt toxins are absent; this selection counterbalances selection that favors an increase in resistance in fields of Bt crops (Gassmann et al., 2009). Fitness costs expressed in heterozygous individuals are nonrecessive; costs expressed only in homozygous resistant individuals are recessive. Nonrecessive fitness costs can delay the evolution of resistance more effectively than recessive fitness costs because alleles that confer resistance to Bt crops are often rare (Gould et al., 1997; Andow et al., 2000; Tabashnik et al., 2006; Mahon et al., 2007), so most resistance alleles in pests targeted by Bt crops are carried by heterozygous individuals. With nonrecessive fitness costs, the fitness of resistant heterozygous individuals is lower than the fitness of susceptible individuals in refuges, and such costs can strongly select for a decline in resistance despite the fact that selection favors resistant individuals on Bt crops (Gassmann et al., 2009). In other words, recessive costs that influence only the rare homozygous resistant individuals are less effective in delaying resistance than nonrecessive costs that influence the more abundant resistant heterozygous individuals.

Incomplete resistance occurs when the fitness of resistant individuals is lower on Bt cultivars than on corresponding non-Bt cultivars (Carrière and Tabashnik, 2001). It occurs because the individuals that do survive on Bt crops are nevertheless affected adversely by Bt toxins (for example, larvae take a long time to develop on the Bt crop, and the resulting moths are smaller and less fecund). Incomplete resistance is found in many species and contributes to delaying the evolution of resistance by reducing the selective differential between resistant and susceptible individuals (Carrière and Tabashnik, 2001; Tabashnik et al., 2005; Crowder and Carrière, 2009).

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The Pyramid Strategy

The first IR crops produced a single Bt toxin. More recently, the "pyramid" strategy has used GE crops that produce two distinct Bt toxins for delaying pest resistance. The pyramid strategy is based on the principle that insects are killed on two-toxin plants as long as they have a susceptibility allele at a resistance locus—a phenomenon called redundant killing (Gould, 1998; Roush, 1998). As resistance alleles are generally rare, the only genotype that has high survival on a cultivar that produces two or more Bt toxins is expected to be extremely rare. Accordingly, the refuge strategy is considered more effective in reducing the heritability of resistance when crops produce more than one Bt toxin than when they produce a single Bt toxin (Gould, 1998; Roush, 1998; Gould et al., 2006). Models suggest that the pyramid strategy is most effective when the majority of susceptible pests are killed by the GE crop, resistance to each Bt toxin is recessive, fitness costs and refuges are present, and selection with one Bt toxin does not cause cross-resistance to another (Gould, 1998; Zhao et al., 2005; Gould et al., 2006). Cross-resistance to Bt occurs when a genetically based decrease in susceptibility to one toxin decreases susceptibility to other toxins.

Changes in Refuge Strategy in the United States

In a process that aims to use scientific knowledge to balance economic and environmental considerations, refuge strategies for Bt corn and cotton mandated by EPA have been improved since the commercialization of these GE crops in 1996. EPA specifies the area, configuration, and types of refuges to be used with specific Bt crops. Changes in refuge requirements have been based on input from academe, farmers, and industry. Some of the changes have made refuge requirements more stringent, while others have eliminated refuge requirements. For example, refuge distance requirements for the use of Bt cotton against pink bollworm were unspecified from 1996 to 2000, unless the percentage of Bt cotton in a county exceeded 75 percent in the previous year (US-EPA, 1998; Carrière et al., 2001). However, on the basis of the principle that refuges must be near Bt crops to promote the desired mating between susceptible and resistant insects, new regulations enacted in 2001 limited the distance between refuges and Bt cotton regardless of the percentage of Bt cotton in the previous year (Tabashnik et al., 1999; Carrière et al., 2001; US-EPA, 2001; Y. Carrière et al., 2004). Since 2006, in response to a proposal from cotton growers to eradicate pink bollworm in Arizona, EPA has allowed use of mass release of sterile pink bollworm moths as an alternative to non-Bt cotton refuges (US-EPA, 2006a).

In another example, in response to a proposal from Monsanto, the refuge requirement of non-Bt cotton cultivars was abolished from Texas to the Mid-Atlantic to manage resistance of tobacco budworm (*Heliothis virescens*) and cotton bollworm (*Helicoverpa zea*) to Monsanto's pyramided Bt cotton cultivar that produces the toxins Cry1Ac and Cry2Ab (US-EPA, 2007) and subsequently to a cultivar from Dow AgroSciences producing Cry1Ac and Cry1F. The proposal included new data and modeling results that indicated that weeds and non-Bt crops other than cotton might provide sufficient refuges to delay Bt resistance in the two mobile, polyphagous pests (US-EPA, 2006b). The 2007 change by EPA meant that refuges of non-Bt cotton are no longer required for millions of acres of the Monsanto cotton cultivar grown in large areas of the United States. Assuming that no other factors changed (e.g., the technology fee), that action would improve the net benefits to farmers of growing the GE cotton and increase its adoption (Luna V et al., 2001; Matus-Cádiz et al., 2004) at least in the short term. However, it is

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noteworthy that decreased susceptibility to both Cry1Ac and Cry2Ab in cotton bollworm (*H. zea*) has indicated that this pest is evolving resistance to cotton producing those toxins in the United States (Tabashnik et al., 2008; Tabashnik et al., 2009b).

It appears likely that most Bt crops commercialized in the future by biotechnology companies will produce two or more Bt toxins for the control of individual insect pest species (Bravo and Soberón, 2008; Matten et al., 2008). That could improve the durability of Bt crops if few other major insect pests targeted by Bt crops evolve resistance before the replacement of one-toxin crops by pyramids, and if populations of pests that are resistant to single-toxin Bt crops remain rare. EPA promotes the replacement of one-toxin Bt cultivars with two-toxin Bt cultivars on the basis of recognition that the evolution of resistance is more effectively delayed with a pyramid strategy than with one-toxin crops (Matten et al., 2008). Another incentive to eliminating the use of one-toxin Bt cultivars when two-toxin Bt cultivars are introduced is that results from simulation models and small-scale laboratory experiments indicate that the evolution of resistance to two-toxin cultivars is accelerated when plants that produce two Bt toxins are grown near plants that produce just one toxin (Roush, 1998; Gould, 2003; Zhao et al., 2005).

So far, the complete replacement of one-toxin with two-toxin Bt cultivars has occurred only in Australia (Baker et al., 2008). The Transgenic and Insecticide Management Strategy committee, which comprises growers, consultants, researchers, seed companies, and chemical industry, has overseen the development, implementation, and evaluation of resistance-management strategies for Bt cotton in Australia (Fitt, 2003). Cotton that produces the Bt toxin Cry1Ac for the control of cotton bollworm (*Helicoverpa armigera*) was replaced by cotton producing Cry1Ac and Cry2Ab in 2004. That allowed producers to reduce the area of refuges from 70 percent with Cry1Ac cotton to as low as 5 percent with Cry1Ac and Cry2Ab cotton (Baker et al., 2008). The exclusive use of a pyramid strategy for managing the evolution of Bt resistance in insect pests might allow producers to use more Bt crops while maintaining efficient resistance management (Mahon et al., 2007; Baker et al., 2008). However, an allele conferring high levels of resistance to Cry2Ab has been found in relatively high frequency (0.0033) in field populations of cotton bollworm (*H. armigera*), and individuals homozygous for this allele can survive on mature cotton producing the toxins Cry1Ac and Cry2Ab (Mahon et al., 2007; Mahon and Olsen, 2009). This indicates that a key assumption of the pyramid strategy is not met (i.e., redundant killing), and thus that caution should be used to manage the evolution of cotton bollworm resistance to Cry1Ac and Cry2Ab cotton in Australia.

Agricultural and Environmental Impacts of Insect Resistance to Bt Crops

The refuge strategy was mandated in the United States not only to slow the evolution of resistance to Bt cultivars but also to protect the effectiveness of Bt sprays. Susceptibility to sprays with many Bt toxins in pests that evolve resistance to single-toxin Bt crops will depend on several factors, including the level of resistance, the variety and concentration of the toxins in the sprays, and the extent of cross-resistance to different toxins. If a spray contains one or more toxins to which the pest has evolved resistance or cross-resistance, susceptibility to the spray could be decreased (Tabashnik et al., 1993; Moar et al., 1995). Nonetheless, sprays containing one or more toxins that kill pests that are resistant to other toxins can be useful against such pests (Tabashnik et al., 1993; Liu et al., 1996; Akhurst et al., 2003; Wang et al., 2007).

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Along with other insecticidal compounds with different modes of action, many sprayed Bt insecticides commonly used in the United States contain at least two Cry toxins that differ substantially from each other in amino acid sequence and that bind to different target sites in the larval midgut (Schnepf et al., 1998; Ferré and Van Rie, 2002; Crickmore et al., 2009). The few pests that have evolved resistance to Bt crops could remain susceptible to sprayed Bt insecticides that contain many Bt toxins, as long as the evolution of resistance to the toxins in Bt crops does not involve strong cross-resistance to all the toxins in Bt sprays. Cross-resistance between Bt toxins that differ substantially in amino acid sequence is usually weak or nil, but exceptions occur in important pests that are targeted by Bt crops, including cotton bollworm (*H. zea*) (Hernández-Martínez et al., 2009; Tabashnik et al., 2009b). However, the possibility of cross-resistance in corn stem borer and fall armyworm has not been investigated extensively. The agricultural and environmental impacts of cross-resistance between single-toxin Bt crops and multitoxin Bt sprays will also depend on the extent to which the two approaches are used to control a given pest and on pest movement between Bt crops and areas where Bt sprays are used.

EPA requires remedial action plans to address cases of resistance, which can involve cessation of use of a particular Bt cultivar in a specific area (US-EPA, 1998; Carrière et al., 2001; US-EPA, 2001). Sales of corn that produce the Bt toxin Cry1F were suspended voluntarily in Puerto Rico after the evolution of resistance to Cry1F in fall armyworm (Matten et al., 2008). In the absence of published information on the distribution of resistance and on the presence of cross-resistance and fitness costs, it is not possible to assess whether the evolution of resistance to Cry1F in fall armyworm threatens the sustainability of other Bt crops or sprayed Bt insecticides in Puerto Rico. Furthermore, the economic and environmental consequences of Bt resistance are difficult to assess because little information is available on the profitability of Cry1F corn in Puerto Rico and on how withdrawal of Cry1F corn in Puerto Rico has affected insecticide use.

In contrast, the evolution of resistance of cotton bollworm (*H. zea*) to Cry1Ac cotton in the United States did not have serious agronomic, economic, or environmental consequences. That is because resistance did not affect many bollworm populations, Cry1Ac cotton still provides some control of Cry1Ac-resistant insects, synthetic insecticides were used in conjunction with Cry1Ac cotton from the onset to control bollworm, and the widespread use of cotton that produces both Cry1Ac and Cry2Ab in the states where resistance occurred provided effective control of insects that were resistant to Cry1Ac (Tabashnik et al., 2008). Data on increased bollworm survival on cotton plants that produce Cry1Ac and Cry2Ab in the field or on the consequences of field-evolved resistance to Cry2Ab are lacking (Tabashnik et al., 2009b). Although there is strong evidence of resistance to Cry1Ac in some populations of bollworm in the Southeast (Tabashnik and Carriere, 2009; Tabashnik et al., 2009a), a subset of the data has been contested by some scientists (Moar et al., 2008), and EPA has not commented on the situation.

GENE FLOW AND GENETICALLY ENGINEERED CROPS

This section presents an overview of the potential of gene flow to weedy relatives for crops for which GE varieties have been developed (though not all of these varieties have been commercialized). The movement of herbicide resistance into weedy relatives present on farm fields can influence farmers' weed-management strategies. Gene flow between GE and non-GE crops could accelerate the evolution of pest resistance to Bt crops, if many Bt plants are routinely present in refuges of non-Bt crops (Heuberger et al., 2009; Krupke et al., 2009). The following

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section specifically considers factors that affect gene flow via cross-pollination within crops, on which the coexistence of GE and non-GE crops depends. Chapter 3 addresses other sources of gene flow, such as co-mingling of seed and germination of volunteer seeds left behind, and the economic consequences of gene flow between GE and non-GE varieties.

Gene Flow Between Genetically Engineered and Non-Genetically Engineered Crops

The potential for cross-pollination between GE and non-GE crops depends on the plant species (Ellstrand, 2003a). In particular, the reproductive strategy of a crop determines the degree of gene flow between GE and non-GE crops; open-pollinated crops (such as corn) have the greatest probability of cross-pollination between GE and non-GE cultivars. Even in self-pollinated plants, out-crossing occurs occasionally, the rate depending on the particular species and environment. In soybean, for example, out-crossing is occasional (Palmer et al., 2001; Abud et al., 2004; Abud et al., 2007). In contrast, corn is freely out-crossing, so the cross-pollination of non-GE cultivars with pollen from GE varieties depends on the distance from the source and other factors. Models of pollen dispersal in corn and the consequent gene flow may have low precision, particularly in light of the small amounts of pollen that move more than 800 ft and the substantial impacts of climate (Ashton et al., 2000).

Among the factors that control gene flow between populations of wind-pollinated plants are distance from the pollen source and pollen shed density, time required for pollen movement, wind speed and direction, air temperature, and relative humidity (Luna V et al., 2001; Westgate et al., 2003). Pollen viability declines quickly with desiccation. Even if pollen is dispersed over great distances, it may, if dried out, not be viable. Similarly, the occurrence of GE pollen in a non-GE corn field does not necessarily mean that pollination will occur (Feil and Schmid, 2002). Nonetheless, the distances needed to prevent any cross-pollination in corn or other open-pollinated crops are so great that they are not practical in current commercial agricultural systems (Luna V et al., 2001; Matus-Cádiz et al., 2004).

Insect-mediated cross-pollination between GE and non-GE crops occurs in those species for which insects typically are the agents of transfer of pollen between individuals (Van Deynze et al., 2005; Llewellyn et al., 2007). Canola and cotton are modally out-crossing as a result of pollinator activity, whereas soybean is usually self-pollinated but is visited by insects seeking its pollen (Ahrent and Caviness, 1994; Walklate et al., 2004; Heuberger and Carrière, 2009). In a recent study that monitored cross-pollination of seed-production fields of non-Bt cotton (some HR, some not) by Bt cotton, both the density of flower-foraging honey bees in seed production fields and the area of Bt cotton at a distance of 2,460 ft from the non-Bt cotton fields affected cross-pollination (Heuberger and Carrière, 2009). It had been documented that most cross-pollination in cotton occurs over distances of less than 160 ft (McGregor, 1976; Free, 1993; Xanthopoulos and Kechagia, 2000; Zhang et al., 2005). Nevertheless, foraging honey bees can easily travel two miles or more (Beekman and Ratnieks, 2000); this suggests that the 2,460-ft radius at which pollen from Bt cotton influenced out-crossing of non-Bt cotton resulted from movement of foraging honey bees from Bt to non-Bt cotton fields. Accordingly, the results of Heuberger and Carrière (2009) indicate that small-scale gene-flow studies may miss occasional long-distance cross-pollination between GE and non-GE insect-pollinated crops.

As the adventitious presence of GE traits is widespread in the seed supply of non-GE crops, gene flow between non-GE and GE crops may commonly involve cross-pollination by plants from the same field (i.e., adventitious plants). Heuberger and Carrière (2009) found adventitious

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Bt cotton plants in 67 percent of seed-production fields of non-Bt cotton. They demonstrated that adventitious Bt plants resulted both from human error (inadvertent planting of Bt cotton in non-Bt cotton fields) and from contamination in seed bags. After accounting for the effect of the area of Bt cotton surrounding a seed production field and the abundance of foraging honey bees, the density of adventitious Bt plants was positively associated with out-crossing rates in seed-production fields. Most models of pollen transfer between crop varieties have not considered the adventitious presence of GE plants in non-GE fields and may therefore fall short of making accurate predictions of the abundance of GE traits in supposedly non-GE plants.

Canola is not a major crop in the United States, but substantial acreage is planted in North Dakota, which accounted for more than 87 percent of U.S. canola planted in 2009 (USDA-NASS, 2009b). Gene flow between GE and non-GE canola is well documented in the large canola-growing region of western Canada; it can be facilitated by the transient populations of canola established each year outside agricultural fields (Knispel et al., 2008). Genetically engineered HR canola cultivars are the dominant type, and in 2006, glyphosate-resistant and glufosinate-resistant canola cultivars accounted 65 percent and 32 percent, respectively, of U.S. canola acres planted (Howatt, 2008, personal communication). Given that there are two GE herbicide-resistance traits (glyphosate and glufosinate) and a non-GE imidazolinone-resistant trait, introgression of these traits can result in multiple-herbicide resistance in a single plant (Knispel et al., 2008). The occurrence of multiple-herbicide-resistant volunteer canola increases the difficulties of management (Beckie et al., 2004; Beckie, 2006; Beckie et al., 2006). In addition to the problem of deploying special management techniques for HR weeds, adventitious presence of a GE trait in a non-GE field of canola has economic consequences.

Alfalfa is an important crop in the United States and is widely cultivated over a broad geographic range (USDA-NASS, 2008). GE glyphosate-resistant alfalfa was commercialized in 2005, and about 198,000 acres were planted in 2006 (Weise, 2007). However, in 2007, it once again became a regulated item, a decision that was upheld by the Court of Appeals in 2008. USDA Animal and Plant Health Inspection Service (APHIS) was ordered to conduct an environmental impact statement (EIS) because of "the significant threat of gene flow and the development of Roundup-resistant weeds that requires further study and analysis in an EIS" (*Geertson Farms Inc.*, 2009).[11] APHIS released the draft EIS for public comment in December 2009.

Sugar beet (*Beta vulgaris*) cultivars with the GE trait that confer resistance to glyphosate have been commercialized and were widely adopted by growers in the United States. However, in September 2009, the Northern California District Court ruled that USDA violated the National Environmental Protection Act when it deregulated HR sugar beets, and USDA is required by the court to prepare an environmental impact statement to adequately consider the impacts of GE sugar beets on other sugar beet growers as well as farmers growing table beets and swiss chard, two crops with which sugar beets may cross pollinate (*Center for Food Safety v. Thomas J. Vilsack*, 2009).

[11]Roundup is the trademarked name of glyphosate sold by Monsanto.

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Gene Flow between Genetically Engineered Crops and Related Weed Species

In locations where crop varieties occur with wild or weedy populations of the same or closely related species, interbreeding between a crop and its relatives may lead to exchange of genes between the cultivars or species involved. Such hybridization is common in plants generally and is a key process for the evolution of new plant species. When gene flow occurs between crops and their wild relatives, an agronomic characteristic may move into the wild populations. Environmental sustainability on farms might be affected by the consequences of such gene flow between crops and wild relatives if the gene flow reduces genetic diversity available for crop improvement. However, only a few crops (sunflower, pecan, blueberry, and some squashes) were domesticated within the borders of the United States, so most crops planted on U.S. farms do not pose a risk to the conservation of genetic diversity in related native species and landraces. When crop species coexist with weedy relatives, gene flow might result in a weed-management issue and any accompanying economic and environmental effects. At least 15 crop species have been documented to hybridize with weedy relatives in the United States (Keeler et al., 1996). For HR traits, hybridization is a mechanism by which herbicide resistance might evolve in related weeds if HR crops are able to interbreed with related weedy species occurring in the same location (see the canola example in "Developing Weed-Management Strategies in Herbicide-Resistant Crops" earlier in this chapter).

In the United States for corn and soybean, the most common GE crops grown, no genetically compatible relatives or weedy strains exist; therefore, movement of GE traits into related weed species is not an issue. Wild populations of cotton (*Gossypium hirsutum*) exist along the Gulf Coast and a wild relative (*Gossypium tomentosum*) is in Hawaii. Gene flow is unlikely because the United States prohibits the commercial sale of Bt cotton in those areas. In Hawaii, test varieties and nursery stock can be produced, but with restrictions to minimize gene flow (e.g., US-EPA, 2005). In contrast, the use of HR crops in the same areas is apparently not more restricted than in the rest of the United States (USDA-APHIS, 2008).

Hybridization between the allotetraploid canola (*Brassica napus*) and one of its diploid weedy parents, turnip mustard (*Brassica rapa*) are extensive, and the hybrids are usually about 60 percent pollen fertile (Warwick et al., 2003; Légère, 2005; Simard et al., 2006), thus facilitating the spread of a GE trait into the weeds. GE herbicide-resistant traits have been reported to persist in populations of turnip mustard as they have in several other species of weeds (Warwick et al., 2003; Owen and Zelaya, 2005; York et al., 2005; Warwick et al., 2008). In addition, hybridization is possible between canola and species of a few related genera of mustards, some of them weedy (Warwick et al., 2000; FitzJohn et al., 2007) and occurs spontaneously when they are grown together in an experimental garden. For these reasons, canola has been designated as a moderate-risk crop with regard to the potential for gene flow to its weedy relatives (Stewart et al., 2003), and farm-level effects may occur in canola-growing regions as discussed earlier. The extent to which they have economic impacts and affect environmental sustainability will depend on how the weeds are managed.

Gene flow has been demonstrated from sugar beet to near-relative weeds, *B. macrocarpa* and *B. vulgaris* subsp. *maritima* (Andersen et al., 2005). Thus, the introgression of HR traits from GE sugar beets to weedy beets (*B. vulgaris*) and sea beets (*B. vulgaris* subsp. *maritima*) should be considered a moderate risk (Stewart et al., 2003), but the consequences of gene flow would occur on a very small spatial scale in the United States. Co-occurrence of those species with sugar beet cultivation was limited to two California counties (Kern and Imperial) in 2006

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(Calflora, 2009). Weedy beets are sporadic and local in the United States and not considered a major problem, as they are in Europe, where the species is native.

Transgenic virus-resistant squash has been available commercially since 1995 and was estimated to have been planted on an average of 12 percent of the 58,400 acres in squash production in 2005 (Quemada et al., 2008). Wild populations of *Cucurbita pepo* occur in south and central regions of the United States (Cowan and Smith, 1993) and can be an agricultural weed (Oliver et al., 1983). Gene flow between conventional cultivars of domesticated *C. pepo* and its wild populations is known to occur (Kirkpatrick and Wilson, 1988; Decker-Walters et al., 2009). Data are not available yet on the extent to which transgenes may exist in wild populations. As of 2005, the opportunity for gene flow across a large spatial scale appeared low because the majority of transgenic squash cultivation occurs outside the range of the wild populations of *C. pepo* (Quemada et al., 2008). The consequences of any gene flow to wild populations depend on virus incidence, the expression of the transgene in the wild populations (Spencer and Snow, 2001; Fuchs et al., 2004a; Fuchs et al., 2004b; Laughlin et al., 2009; Sasu et al., 2009)

Concerns about the consequences of a transfer of GE traits to wild or weedy populations and how to effectively mitigate those consequences have delayed the release of GE sunflower (*Helianthus annuus*, a species that was domesticated in the United States), creeping bentgrass (*Agrostis stolonifera*, a popular turf grass introduced from Europe), and rice (*Oryza sativa*, a species native to Asia with related, intercompatible weeds introduced into some rice fields with the crop). For sunflower, the potential for transgene movement to weedy relatives is quite high and thus the consequences of gene flow on weed management presents an environmental concern about the commercial development of transgenic sunflower (Snow and Palma, 1997; Snow, 2002; Ellstrand, 2003b; Stewart et al., 2003). Wild sunflowers are weeds in row-crop fields, including corn, soybean, domesticated sunflower, wheat, and small grains (Bernards et al., 2009). In a multiyear study conducted across the High Plains of the United States in a number of commercial sunflower-production fields, it was observed that approximately 66 percent of the fields existed near weedy sunflower (Burke et al., 2002). It is important that the cultivated and weedy sunflowers flowered simultaneously (52–96 percent), and evidence of hybridization ranged from 10 percent to 33 percent of the weedy sunflower (Burke et al., 2002). Evidence of genes coding for herbicide resistance in cultivated sunflower moving to weedy sunflower suggests that there is a substantial risk of the introgression of the trait into wild sunflower populations, which might result in increased management problems for growers if the wild plants are in cultivated fields (Marshall, 2001; Massinga and Al-Khatib, 2002; Massinga, 2003). These management problems may emerge in association with sunflower varieties with resistance to the herbicide imazamox that were developed using conventional breeding methods and not genetic engineering. Hybrids of imazamox-resistant sunflowers and two interbreeding relatives appear to be competitively equal to the HR domesticated sunflower, suggesting that the resistance gene will persist when gene flow occurs (Massinga et al., 2005).

GE glyphosate-resistant creeping bentgrass was field-tested in Oregon in 2003, and introgression of the transgene into weedy populations was detected at a considerable distance from the test sites (Mallory-Smith et al., 2005; Reichman et al., 2006). The inability to mitigate GE trait introgression into compatible weedy relatives of creeping bentgrass has delayed commercialization of the GE creeping bentgrass product (Charles, 2007). The transfer of this trait may be important if glyphosate is used to control weedy populations of the grass.

In the case of rice, GE glufosinate-resistant rice cultivars have been developed to improve weed management of red rice (*Oryza sativa* L.), a common and important weed in commercial

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rice production. However, these GE cultivars have never been commercially available (Gealy et al., 2007) though they were first deregulated in 1998. The commercialization of rice with resistance to the herbicide imazethapyr (produced by a chemical-induced seed mutagenesis, not genetic engineering) has resulted in the movement of this HR trait into red rice because total control of red rice is not always possible (Burgos et al., 2008). Stewardship recommendations to prevent and to control the spread of HR red rice exist and encourage crop diversity (BASF, 2009); data on the success of managing imazethapyr-resistant red rice may provide useful information for the regulation of GE cultivars. In addition to concerns about introgression with the weed red rice, GE rice has historically been unacceptable to consumers for the reasons discussed in Chapter 1 (Gealy and Dilday, 1997; Gealy et al., 2003; Gealy et al., 2007).

Wheat is a major grain crop in the United States, and there has been interest in commercializing genetically engineered HR cultivars. The potential for introgression of a GE trait into near-relative weed populations exists (Ellstrand et al., 1999; Morrison et al., 2002; Morrison et al., 2002; Stewart et al., 2003). Jointed goatgrass (*Aegilops cylindrica*) is reported to be an important weed of small grains in Colorado, Kansas, New Mexico, Oklahoma, Oregon, Utah, Washington, and Wyoming (NAPPO, 2003) and is a weed in the Great Plains (Stubbendieck et al., 1994). Specifically, it causes serious problems in winter wheat in the western United States due to its similarity to wheat in appearance, seed size, growth pattern, and genetics (Schmale et al., 2008; Schmale et al., 2009; Yenish et al., 2009). Studies have demonstrated hybridization with wheat varieties (Hanson et al., 2005; Rehman et al., 2006). It is predicted that hybridization between HR wheat cultivars and *Aegilops* spp. will result in the introgression of the HR trait and thus a more competitive weedy hybrid, complicating management issues in wheat production (Hanson et al., 2005; Loureiro et al., 2008). Glyphosate-resistant hard red spring wheat provided an opportunity for better weed management and resulted in a 10-percent higher grain yield than conventional wheat cultivars treated with conventional herbicides (Howatt et al., 2006). Despite the technical fit, the program to develop glyphosate-resistant cultivars was postponed in 2004 because of regulatory and marketing issues, concern for stewardship, and the inability to ensure the segregation of the GE wheat from non-GE wheat grain at the time (Dill, 2005) (see Chapter 4 for further details). An imazamox-resistant winter wheat, which was bred using conventional techniques, has been commercially available since 2002, and the identical concerns about the development of HR jointed goatgrass biotypes exist (Kniss et al., 2008).

The ecological and economic consequences of the introgression of GE traits into weedy or native relatives will vary among types of GE traits (Owen, 2008). For HR crops, the introgression of herbicide resistance from GE crops into weedy near-relatives is likely to have consequences for weed management *when* weeds with the resistance trait occur in fields or other ecosystems treated with the herbicide. Therefore, for future HR plants, understanding the extent to which a herbicide controls weedy relatives will provide valuable information on the consequences of gene flow for on-farm and off-farm weed management.

CONCLUSIONS

Environmental effects at the farm level have occurred as a result of the adoption of GE crops and the agricultural practices that accompany their cultivation. The introduction of GE crops has reduced pesticide use or the toxicity of pesticides used on fields where soybean, corn, and cotton are grown. Available evidence indicates that no-till practices and HR crops are complementary,

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and each has encouraged the other's adoption. Conservation tillage, especially no-till, reduces soil erosion and can improve soil quality. The pesticide shifts and increase in conservation tillage with GE crops have generally benefited farmers who adopted them so far. Conservation tillage practices can also improve water quality by reducing the volume of runoff from farms into surface water, thereby reducing sedimentation and contamination from farm chemicals. Given that agriculture is the largest cause of impaired quality of surface waters, that may constitute the largest benefit of GE crops, but the infrastructure for tracking and understanding this does not exist.

The effects of Bt crops on nontarget invertebrates, including predators, are favorable or neutral, depending on the degree to which Bt crops replace insecticide treatment and on whether additional insecticide treatments are applied to the Bt crop. Evidence indicates no effect of Bt toxins on the honey bee, a widespread pollinator in agricultural systems. For HR crops, the effects on the abundance of arthropods in the fields correlate with whether weeds are controlled more effectively. Shifts in the weed communities have occurred in response to weed-management tactics used for HR crops, in particular when weeds in glyphosate-resistant crops are treated only with glyphosate. Similarly, glyphosate-resistant weeds have evolved where the glyphosate application is repeated and constitutes the only weed-management tactic used. The evolution of resistance to glyphosate in particular kinds of weeds and shifts in the weed community may increase production costs for farmers, require more tillage for weed control, and lead to at least a partial return to the use of different and often more toxic herbicides. The development and establishment of more diversified control strategies for managing weeds in HR crops is needed.

The first generation of IR crops commercialized in the United States produced a single Bt toxin for the control of insect pests. Since the commercialization of those crops, EPA has mandated the refuge strategy to delay the evolution of resistance in major insect pests that are controlled by Bt corn and cotton. After 14 years of use of Bt crops, two insect pests have evolved resistance to Bt crops in the United States: cotton bollworm (*Helicoverpa zea*) evolved resistance to Cry1Ac and Cry2Ab in Bt cotton, and fall armyworm evolved resistance to Cry1F in Bt corn. The evolution in bollworm of resistance to Bt cotton did not have serious agronomic, economic, or environmental consequences. Information for assessing the consequence of the evolution of resistance to Cry1F in Bt corn in fall armyworm is lacking. The second generation of IR crops produces two or more Bt toxins for the control of individual insect pest species. The complete replacement of one-toxin with multitoxin Bt crops should help in delaying the evolution of insect-pest resistance to IR crops.

The changes in weed and insect population densities resulting from the adoption of HR and IR crops can affect farms beyond the boundaries of the operations that are using the GE crops. That is, farming practices may have landscape as well as local level effects on pest populations. For example, large-scale planting of IR crops has decreased populations of some insect pests targeted by Bt crops not just at a farm-field level but on a regional scale. It can also affect local and possibly landscape populations of non-target or beneficial organisms according to crop species planted and management of pests, nutrients, water, and soil (Björklund et al., 1999; Cattaneo et al., 2006; Dale and Polasky, 2007; Zhang et al., 2007; Carrière et al., 2009). Beneficial organisms with high mobility move among habitats and crop fields, so effects within a field that is planted to GE crops could influence beneficial organisms on other farms as well as noncultivated habitats in the region.

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For corn and soybean, gene flow between GE varieties and wild relatives is not an issue in the United States because corn and soybean have no wild relatives here. Limited overlap occurs between cotton and wild relatives and between sugar beet and introduced, weedy relatives. Gene flow is unlikely for Bt cotton and wild relatives because of planting restrictions, but there are no planting restrictions for HR cotton. Other crops in which gene flow with wild or weedy relatives is possible include canola, alfalfa, sunflower, creeping bentgrass, wheat, and rice. Gene flow between GE and non-GE crops occurs via cross-pollination between GE and non-GE plants from different fields, co-mingling of seed before or during the production year, and germination of seeds that are left behind after the production year. Gene flow between GE and non-GE crops is almost impossible to prevent completely with current technology. The complex interactions among the multiple factors that influence gene flow between GE and non-GE crops and the resulting levels of adventitious presences of GE traits in non-GE crops deserve more attention.

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3

Farm-Level Economic Impacts

As shown in Chapter 1, farmers growing soybean, cotton, and corn adopted genetically engineered (GE) varieties over the last decade on the majority of acres planted to these crops in the United States. Much smaller acreages were planted in 2009 to a few other GE crops, such as canola, sugar beet, squash, and papaya. The decision to plant GE crops has affected the economic circumstances not only of the adopting farmers but in some cases of farmers who chose not to adopt them. The economic effects on farmers who adopt GE crops span their production systems and marketing decisions. In this chapter, we discuss the potential yield effects, changes in overhead expenses and management requirements, and shifts in market access and value of sales. A wide array of studies conducted mostly during the first 5 years of adoption has provided evidence for assessing the overall economic implications for farmers (see Box 3-1). We also discuss here the economic effects of GE-crop use on livestock producers who use the crops for feed and on farmers who do not elect to use the technology. The chapter concludes by examining the economic implications of gene flow from GE crops to non-GE crops and weedy relatives.

ECONOMIC IMPACTS ON ADOPTERS OF GENETICALLY ENGINEERED CROPS

GE crops have affected the economic status of adopters in several ways. The use of GE crops has had an effect on yields and their risk-management decisions. Genetic-engineering technology has also changed farmers' production expenses and altered their decisions related to time management. Furthermore, because of the widespread adoption of GE crops and their subsequent impact on yields, genetic-engineering technology has influenced the prices received by U.S. farmers.

Yield Effects

The first generation of GE varieties contains traits that control or facilitate the control of pest damage. A starting point for analyzing the productivity effect of such control is the damage-control framework (Lichtenberg and Zilberman, 1986) that was developed to estimate the effectiveness of the use of chemical pesticides and other pest-control activities. The framework

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recognizes that damage-control agents, like pesticides and GE traits for pest management, have an indirect effect on yield by reducing or facilitating the reduction of crop losses, in contrast with such inputs as fertilizers, capital, and labor, which affect yields directly. In particular, the framework assumes that

$$\text{effective yield} = (\text{potential yield})(1 - \text{damage}).$$

Potential yield is defined as the yield that would be realized in the absence of damage caused by pests (i.e., weeds, insects).[1] It is a function of production inputs, such as water and fertilizer, and of agroecological conditions and seed varieties. The yield actually observed is called effective yield and is equal to potential yield minus damage. Damage is affected by the pervasiveness of pests, which may be controlled with pesticides, the adoption of GE varieties, or other control activities. With that framework, the yield effects of GE varieties can be analyzed, but spatial, temporal, and varietal factors must be taken into consideration.

BOX 3-1
Measuring Impacts

To evaluate the economic impacts of GE crops on adopters and nonadopters, the committee relied on the results of empirical analyses of farmer surveys and market data. Studies were peer reviewed, but the research approach and methods varied considerably with each study's purposes and data. Each study has its own strengths and limitations. For example, some studies may use a different guideline in judging the significance (i.e., confidence level) of factors affecting the adoption of GE crops compared to other studies. The committee could not make the various studies comparable and accepted each set of findings as valid evidence. Some of the general approaches used to estimate economic impacts are explained here.

Empirical data. A comparison of means or averages is sometimes used to analyze results from experiments in which factors other than the item of interest are "controlled" by making them as similar as possible. For example, means of yield or pesticide use can be compared for two groups of soybean plots that are similar in soil type, rainfall, sunlight, and all other respects. One of the two groups is considered to have a *treatment* (e.g., soybean with a genetically engineered trait), and the other does not (e.g., conventional soybean). As an alternative to controlled experiments, the subjects that receive treatment and those that do not can be selected randomly with data collected through mail, phone, internet, or personal surveys.

Survey data. Caution must be exercised in interpreting the results obtained by analyzing the differences in means from data from "uncontrolled experiments," such as farm surveys. Conditions other than the "treatment" are not equal across the farms surveyed. For example, differences between mean estimates for yield and pesticide use from survey results cannot necessarily be attributed to the use of GE seeds because the different results are influenced by many other factors which are not controlled, including irrigation, weather, soil, nutrient and pest-management practices, other cropping practices, operator characteristics, and pest pressures.

[1]Damage may also be caused by weather conditions, such as wind, rain, drought, and frost. For succinctness and convenience here, the definition of damage is restricted to pest problems.

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Moreover, farmers are not assigned randomly to the two groups (adopters and nonadopters) but make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different as groups, and these differences may manifest themselves in farm performance. They could be confounded with differences due to the adoption of GE crops (i.e., the treatment). This situation, called self-selection, would bias the statistical results unless it is recognized and corrected.

However, farmer surveys give a more accurate picture of the total farm-level economic effects of GE-crop adoption in terms of the secondary behavioral changes resulting from adoption (e.g., adoption of conservation tillage and changes in the timing of pesticide application). Moreover, it is rarely the case that a farmer would or could choose to adopt a GE cultivar to replace a non-GE cultivar that is an isoline or near-isoline, so relying on agronomic experimental data to measure the economic differences can be biased. Also, only farmer surveys can reveal the value of the changes in nonpecuniary characteristics that can occur with the adoption of GE cultivars.

Social scientists often are able to statistically control for certain influencing factors for which there are data (apart from the GE-crop treatment) by using multiple regression techniques in econometric models. That is, differences in economic conditions and crop or management practices that also influence yield or other outcomes are held constant so that the effect of adoption can be isolated. For example, in research on GE crops, economists control for many factors, including output and input prices, pest infestation levels, farm size, operator characteristics, and management practices such as crop rotation and tillage. In addition, economists control for self-selection and simultaneity (of GE adoption and pesticide use decisions) using particular types of econometric models. To account for simultaneity of decisions and self-selectivity, a two-stage model may be used. The first stage consists of the adoption-decision model for GE crops. The second stage then uses the findings from the first stage to examine the impact of using GE crops on yield, farm profit, and pesticide use.

The Counterfactual. Ideally, measuring the impact of a treatment requires the observation of the results that would emerge in the absence of the treatment: a *counterfactual*. Aside from controlled experiments, it is not possible to observe this counterfactual outcome. Rather, the counterfactual is inferred by methods such as those summarized above (e.g., controlling for all other influencing factors). Moreover, regarding environmental impacts, Ferraro (2009) argues that "elucidating casual relationships through counterfactual thinking and experimental or quasi-experimental designs is absolutely critical in environmental policy and that many opportunities for doing so exist." The use of the two-stage estimation procedure to correct for selection bias exemplifies such a quasi-experimental design. However, Ferraro also admits that "not all environmental programs are amenable to experimental or quasi-experimental design." In those cases, firm conclusions cannot be drawn about the causative factors inducing GE-crop adoption or other outcomes of interest.

Indirect Yield Effects

The indirect yield effects of the use of insect-resistant (IR) crops are most pronounced in locations and years in which insect-pest pressures are high. For example, it is generally recognized that the adoption of Bt corn for European corn borer (*Ostrinia nubilalis*) control resulted in annual average yield gains across the United States of 5-10 percent (Falck-Zepeda et al., 2000b; Carpenter et al., 2002; Fernandez-Cornejo and McBride, 2002; Naseem and Pray, 2004; Fernandez-Cornejo and Li, 2005). Empirical studies, however, have clearly indicated that the indirect yield effects of Bt corn hybrids for European corn borer control vary temporally and spatially. In years with high pressure—corn borer damage of more than one tunnel per plant that

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exceeds 2 inches in length (Baute et al., 2002; Dillehay et al., 2004)—the yield advantage for Bt hybrids relative to near-isolines[2] was 5.5 percent in Pennsylvania and Maryland (Dillehay et al., 2004), 6.6 percent in Wisconsin (Stanger and Lauer, 2006), 8 percent in New Jersey and Delaware (Singer et al., 2003), 9.4 percent in Iowa (Traore et al., 2000), and 9.5 percent in South Dakota (Catangui and Berg, 2002). The yield advantage for Bt corn was negligible in those regions during years with low pest pressure (Traore et al., 2000; Catangui and Berg, 2002; Singer et al., 2003; Dillehay et al., 2004; Stanger and Lauer, 2006). Likewise, in regions where European corn borer is an occasional pest, there was no indirect yield advantage from the use of Bt hybrids in comparison to near-isolines (Cox and Cherney, 2001; Baute et al., 2002; Ma and Subedi, 2005; Cox et al., 2009). Most of the early empirical studies, however, included some Bt events[3] that did not have season-long control of corn borer, and this may have muted the yield advantage of Bt hybrids (Traore et al., 2000; Catangui and Berg, 2002; Pilcher and Rice, 2003).

There have been fewer empirical studies of the yield effects of Bt corn for control of corn rootworm (*Diabrotica* spp.) than of the effects of Bt corn for control of European corn borer. Rice (2004) estimated potential annual benefits if 10 million acres of Bt corn for corn rootworm control were planted. They included

- Intangible benefits to farmers (safety because of reduced exposure to insecticides, ease and use of handling, and better pest control).
- Tangible economic benefits to farmers ($231 million from yield gains).
- Improved harvesting efficiency due to reduced stalk lodging.
- Increased yield protection (9 to 28 percent relative to that in the absence of insecticide use and 1.5 to 4.5 percent relative to that with insecticide use).
- Reduction in insecticide use (a decrease of about 5.5 million pounds of active ingredient per 10 million acres).
- Increased resource conservation (about 5.5 million gallons of water not used in insecticide application).
- Conservation of aviation fuel (about 70,000 gallons not used in insecticide application).
- Reduced farm waste (about 1 million fewer insecticide containers used).
- Increased planting efficiency.
- Improved safety of wildlife and other nontarget organisms.

A recent study by Ma et al. (2009) indicated spatial and temporal variability in indirect yield responses. Bt corn rootworm hybrids produced yields 11-66 percent larger than untreated near-isoline hybrids. Bt yields were also larger than yields of the non-Bt hybrid variety planted on clay soils and treated with insecticide in 1 of 3 years that had high infestations of western corn rootworm (*Diabrotica virgifera virgifera*). On sandy soils, where corn rootworm infestations are typically much lower than on clay soils, yield differences also occurred between Bt corn rootworm hybrids and their near-isolines with or without the standard soil-applied insecticide

[2]Near-isolines are cultivars that have the same or near genetic constitution (except for alleles at one or a few loci) as the original cultivar from which they were developed. Near-transgenic isolines that have similar genetic makeup except for the transgenic trait allow a comparison of the cultivar with or without the transgene for its agronomic, quality, or nutritional aspects.

[3]Each seed company has different events associated with different insertion places of the Bt gene and different promoter genes that allow a Bt toxin to be produced at different times of the season or in different plant parts.

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treatment in 1 of 2 years. The study reported low levels of western corn rootworm on droughty sandy soil, however, and attributed yield increase to improved drought tolerance from the finer, longer fibrous roots of the Bt hybrid corn. Cox et al. (2009) found no yield advantage for corn hybrids with Bt rootworm control compared with near-isolines in a dry year when rootworm damage did not occur.[4]

Gray et al. (2007) expressed concern that one of the Bt corn rootworm events was somewhat susceptible to injury by a variant of western corn rootworm in Illinois. Another Bt corn rootworm event, however, had superior control of western corn rootworm larvae in Iowa, Illinois, and Indiana (Harrington, 2006); this suggests that distinct Bt events from different seed companies may differ somewhat in corn rootworm control as they did initially in corn borer control. Cox et al. (2009) evaluated both Bt rootworm events on second-year corn in field-scale studies on four farms in New York and found that neither rootworm event provided a yield advantage because rootworm occurrence was low in all fields. As with Bt corn for corn borer, Bt corn for rootworm control did not provide an indirect yield benefit in the absence of pest pressure.

Piggott and Marra (2007), relying on 1999–2005 university field-trial data from North Carolina, found that Bt cotton with two endotoxins out-yielded conventional cotton by 128 more lbs of lint per acre (14 percent of average yield in the region) and out-yielded Bt cotton with one endotoxin by 80 lb/acre (8 percent of average regional yield). A study of Bt cotton varieties with two endotoxins in 13 southern locations that had mostly moderate to high infestations of cotton bollworm (*Helicoverpa zea*), with or without foliar-applied insecticides, showed that indirect yield effects had spatial variability. The Bt cotton cultivars without insecticide use provided consistent control of the *Heliothines* (cotton bollworm and tobacco budworm, *Heliothis virescens*), regardless of the magnitude of infestation (Siebert et al., 2008). Furthermore, supplemental insecticide applications to the Bt cotton cultivars rarely improved control of budworm and bollworm. In the low-infestation environments, however, the use of Bt cultivars with or without insecticides provided no yield improvement relative to the control or the non-Bt cultivar without insecticide application. In the moderate- to high-infestation environments, the Bt cultivars provided the same 30-percent yield increase in lint yield with or without insecticides compared with the control (Siebert et al., 2008). In a large-scale study of 81 commercial cotton fields conducted in 2002 and 2003, average yield did not differ among Bt cotton, Bt cotton resistant to glyphosate, and non-GE cotton (Cattaneo et al., 2006). However, after statistical control for variation in two factors significantly associated with yield (number of applications of synthetic insecticide and seeding rate), the yield of Bt cotton and Bt cotton with herbicide resistance was significantly larger (by 8.6 percent) than the yield of non-GE cotton. A total of eight GE cotton cultivars and 14 non-GE cultivars were included in the study. For those

[4]As discussed in Chapter 1, all Bt rootworm corn hybrids are treated with a low level of insecticide and fungicide (typically a neonicotinoid). The low level (0.25 mg of active ingredient per seed) targets secondary pests but does not affect corn rootworm. In fields planted continuously with corn, the low level used with a soil-applied insecticide resulted in lower corn yields compared to a high level (1.25 mg of active ingredient per seed) with a soil-applied insecticide (Cox et al., 2007c). That is indirect evidence that the high level of seed-applied insecticide increases control of corn rootworm, but the low level does not. In addition, the low and high levels of seed-applied insecticides had no positive effects on corn grain (Cox et al., 2007b) or corn silage yields (Cox et al., 2007a) when following soybeans, which suggests there is no yield enhancement of these seed-applied insecticides in the absence of pests.

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cultivars, it appears that Bt cotton (herbicide-resistant or not) would generally out-yield non-Bt cotton given similar production inputs and agronomic conditions.

The indirect yield effects of herbicide-resistant (HR) crops generally may have less spatial and temporal variability because weeds are ubiquitous and cause yield losses in most situations. For example, the use of HR soybean with timely glyphosate application almost always achieves yield gains relative to production without weed control (Tharp and Kells, 1999; Corrigan and Harvey, 2000; Mulugeta and Boerboom, 2000; Wiesbrook et al., 2001; Knežević et al., 2003a, b; Dalley et al., 2004; Scursoni et al., 2006; Bradley et al., 2007; Bradley and Sweets, 2008). Likewise, the use of HR corn and cotton varieties with timely glyphosate application almost always results in yield increases (Culpepper and York, 1999; Johnson et al., 2000; Gower et al., 2002; Dalley et al., 2004; Richardson et al., 2004; Sikkema et al., 2004; Thomas et al., 2004; Cox et al., 2005; Myers et al., 2005; Sikkema et al., 2005; Cox et al., 2006; Thomas et al., 2007).

Yield Lag and Yield Drag

Despite properties that result in indirect yield benefits, some farmers observed a yield reduction when they first adopted HR varieties (Raymer and Grey, 2003). Indeed, shortly after the adoption of glyphosate-resistant soybean, university soybean trials reported lower yields of HR varieties (Oplinger et al., 1998; Nielsen, 2000). In a study that compared five HR varieties with five non-HR varieties in four locations in Nebraska, evidence of "yield lag" and "yield drag" was found (Elmore et al., 2001a, b).[5] A 5-percent yield lag was due to the difference in productivity potential between the older germplasm used to develop the HR varieties and the newer, higher yielding germplasm of the non-HR varieties.[6] A 5-percent yield drag resulted from the reduced production capacity of the soybean plant following the presence or insertion process of the HR gene (Elmore et al., 2001b). Although not as pronounced as in the Nebraska study, Bertram and Petersen (2004) also presented data that indicated a potential yield lag at one location in Wisconsin with the early HR soybean varieties.

Fernandez-Cornejo et al. (2002b) reported that a national farm-level survey indicated that HR soybean showed a small advantage in yield over conventional soybean, probably because of better weed control. A national survey of soybean producers in 2002 found that there was no statistical difference in yield between conventional soybean and HR soybean (Marra et al., 2004). A mail survey of Delaware farmers in 2001 found that HR soybean had a 3-bushel/acre

[5]Yield lag is a reduction in yield resulting from the development time of cultivars with novel traits (in this case, glyphosate resistance and Bt). Because of the delay between the beginning of the development of a cultivar with a novel trait and its commercialization, the germplasm that is used has lower yield potential than the newer germplasm used in cultivars and hybrids developed in the interim. Consequently, the cultivars with novel traits have a tendency to initially yield lower than new elite cultivars without the novel traits. Over time, the yield lag usually disappears.

Yield drag is a reduction in yield potential owing to the insertion or positional effect of a gene (along with cluster genes or promoters). This has been a common occurrence throughout the history of plant breeding when inserting different traits (e.g., quality, pest resistance, and quality characteristics). Frequently, the yield drag is eliminated over time as further cultivar development with the trait occurs.

[6]During selection for a particular trait in a plant-breeding program, many other traits may also change. Such "correlated" changes may occur because a gene controls more than one trait (pleiotropy), because genes controlling two traits are in physical proximity on a chromosome (linkage), or because of random segregation (drift). The distinctions among the three causes are important because the solutions to them differ. Solutions may be necessary because some correlated changes are undesirable.

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yield advantage (Bernard et al., 2004). The survey data and results of empirical studies in Wisconsin indicate that the use of more elite germplasm in variety development has probably eliminated the yield lag or yield drag associated with the use of HR varieties (Lauer, 2006).

Similarly, early empirical studies of Bt corn hybrids indicated a potential yield lag, as indicated by the lower yield of Bt hybrids than of new elite hybrids (Lauer and Wedberg, 1999; Cox and Cherney, 2001). However, Bt hybrids yielded as well as or better than near-isolines (Lauer and Wedberg, 1999; Traore et al., 2000; Cox and Cherney, 2001; Baute et al., 2002; Dillehay et al., 2004), and this suggests that there was no yield drag or loss of yield because of the insertion of the Bt gene with the early Bt corn hybrids.

Furthermore, whether a yield loss or a yield increase materializes for a GE crop depends on the particular farming situation. For example, in their comparison of HR corn hybrids with non-HR varieties, Thelan and Penner (2007) reported that in low-yield environments HR hybrids yielded 5 percent more than non-HR hybrids and in high-yield environments non-HR hybrids yielded about 2 percent more than HR hybrids. An early study of cotton (May and Murdock, 2002) that compared first-generation glyphosate-resistant cultivars with nonresistant cultivars showed no yield lag in glyphosate-resistant cultivars and a yield advantage of using glyphosate instead of the standard conventional soil-applied herbicides. The results of the study suggested that the use of soil-applied herbicides resulted in some type of injury to cotton, whereas glyphosate application before the fourth leaf stage did not. A study at nine locations across the United States (May et al., 2004) showed that one of Monsanto's later glyphosate-resistant cotton lines provided even greater yield than the first-generation glyphosate-resistant cotton when glyphosate was applied from the fourth to the 14th leaf stage; this resulted in an agronomic advantage of the later technology.

A 2002 U.S. Department of Agriculture (USDA) survey found that increases in cotton yields in the Southeast were associated with the adoption of HR cotton and Bt cotton in 1997: a 10-percent increase in HR-cotton acreage led to a 1.7-percent increase in yield and a 10-percent increase in Bt cotton acreage led to a 2.1-percent increase in yield if other productivity-influencing factors were constant (Fernandez-Cornejo and Caswell, 2006).

It was noted above that most of the yield studies of GE versus non-GE crops conducted in the United States used data from the late 1990s and early 2000s.[7] Any yield differences between GE and non-GE varieties found during the first 5 years of adoption could have diminished as seed companies developed new IR and HR events. One reason for the lack of recent studies on yields may be that it is increasingly difficult to find sufficient data on non-GE varieties owing to the predominance of GE varieties in major crops (see Chapter 4).

Improved Crop Quality and Risk Management

Bt corn has been found to decrease concentration of the toxic chemical aflatoxin (Wiatrak et al., 2005; Williams et al., 2005) and some other mycotoxins produced by fungi (fumonisins in particular) in the grain (Clements et al., 2003). In doing so, it decreases the risk of price dockage to farmers because of poor crop quality and increases food safety for consumers. Bt crops also have reduced stalk lodging at harvest (Rice, 2004; Wu et al., 2005; Stanger and Lauer, 2006;

[7]More recent data from field trials are available but have not been published in peer-reviewed literature.

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Wu, 2006);[8] this improves crop quality and increases harvest efficiency, thus reducing the farmers' fuel and labor costs. Another benefit of the use of HR soybean is that the presence of foreign matter (such as weed seeds) in the harvested crop has greatly decreased (from 5-25 percent to 1-2 percent in the southeastern states) (Shaw and Bray, 2003), reducing the need for handlers to blend soybean with high foreign matter with soybean with lower foreign matter to improve the overall quality of the crop.

The use of GE crops can also reduce agronomic risks for farmers. For example, in the case of HR crops, glyphosate breaks down quickly in the soil, removing the potential for the residual herbicide to injure a succeeding crop (Scursoni et al., 2006). Additionally, some Bt varieties may improve drought tolerance (Wilson et al., 2005). Empirical studies have not documented that the use of Bt corn for corn borer provides a yield benefit in the presence of drought (Traore et al., 2000; Dillehay et al., 2004; Ma et al., 2005), but Ma et al. (2009) found in an empirical study on Bt corn for corn rootworm that in a drought year on sandy soil, the Bt corn rootworm hybrid yielded 10 percent more than the near-isoline. The roots of the Bt corn rootworm hybrids were longer and more dense than those of the non-GE hybrid because the Bt trait kills the below-ground larvae that feed on the roots of the corn plant. Ma et al. (2009) speculated that Bt corn rootworm hybrids may have more drought tolerance than standard hybrids in drought years because the root system is more intact and therefore capable of taking up more water. Such risk reduction may explain in part farmers' motivation to adopt these GE crops. A related risk posed by adoption of Bt corn in northern latitudes, however, is the potential for higher grain moisture at harvest because of improved plant health, which increases drying costs or delays harvest (Pilcher and Rice, 2003; Dillehay et al., 2004; Ma and Subedi, 2005; Cox et al., 2009).

Because GE crops have the ability to reduce yield loss, adopting farmers also have different insurance options for managing risk. In 2007, Monsanto developed a submission to the USDA Federal Crop Insurance Corporation for a new crop-insurance endorsement for corn that contains three traits: a Bt toxin that controls corn borer, one that controls corn rootworm, and herbicide resistance.[9] The submission proposed a premium-rate discount for those hybrids based on several thousand on-farm field trials conducted over several years in the Corn Belt states of Illinois, Indiana, Iowa, and Minnesota. The trials demonstrated the yield and yield-risk reduction advantages of the hybrids compared with conventional or single-trait HR hybrids and showed that the current premium rates were no longer actuarially appropriate. A lower insurance premium became available in the 2008 crop year to farmers who adopted the triple-stacked hybrids. The rate discount was applied to the yield portion of the premium for actual production history of the field and based policies on crop-insurance units in which at least 75 percent of the acreage was planted to qualifying corn hybrids. The average premium-rate discount was 13 percent in 2008, or about $3.00/acre.

Comparable triple-stacked hybrids from seed companies Dupont/Pioneer and Syngenta were approved for inclusion in the program for the 2009 crop year, and the premium-rate discount applies to all three companies' and licensees' seed brands that contain at least the above-mentioned traits for dryland corn in at least a subset of 13 Midwest states and irrigated corn in

[8]Stalk lodging is the permanent displacement of the stems of crops from their upright position, resulting in a crop that either leans or can be prostrate. A mildly lodged crop results in only a slight slowdown of harvest, whereas a severely lodged crop greatly slows down harvest (in some instances the crop can only be harvested in one direction further reducing harvesting efficiency).

[9]These products are marketed by Monsanto as YieldGard® Plus, Roundup Ready 2®, and YieldGard ® VT Triple hybrids.

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Kansas and Nebraska. This is the first approved crop-insurance innovation that has resulted in reduced premium rates, and it provides a saving for farmers and reduces the need for premium subsidies by the federal government. Cox et al. (2009), however, found no consistent yield or economic advantage for triple-stacked hybrids compared to double-stacked hybrids from both companies in second-year corn in New York, despite one of the years being dry and warm. In both years, corn rootworm damage was low, and corn borer damage was sporadic across locations.

Production Expenses

The use of GE crops triggers changes in several production expenses, particularly those related to seed technology, pesticide expenditures, labor and management requirements, and machinery operations.

Seed Prices

U.S. farmers pay for the GE traits in the seeds that they plant in the form of a technology fee because GE seeds are considered proprietary in the United States. The market price of seed, which includes the technology fee, incorporates the costs associated with development, production, marketing, and distribution (Fernandez-Cornejo and Gregory, 2004). The price must be responsive to farmers' willingness to purchase the technology while ensuring an attractive return on capital to the seed development firms (technology provider and licensee seed companies or distributors) and their investors. The price also depends on the competitiveness of the particular seed market and on the pricing behavior of firms that hold large shares of the market.

In recent decades, private-sector research and development costs have risen with the application of new technologies. Much of the increase in seed prices paid by U.S. farmers has been associated with that general trend (Krull et al., 1998). The seed-price index has exceeded the average index of prices paid by U.S. farmers by nearly 30 percent since the introduction of GE seeds in 1996 (Figure 3-1). The contrast is even starker for cotton and soybean. After adjustment for inflation, the real average cotton seed price almost tripled between 1996 and 2007 (Figure 3-2), while the soybean seed price grew by more than 60 percent.

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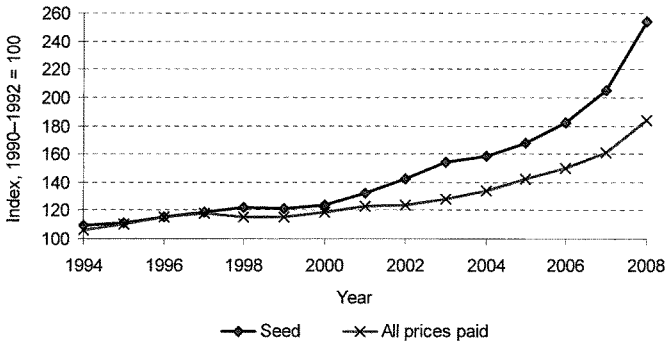


FIGURE 3-1 Seed price index and overall index of prices paid by United States farmers.
SOURCE: Fernandez-Cornejo, 2004; USDA-NASS, 2000, 2005, 2009a.

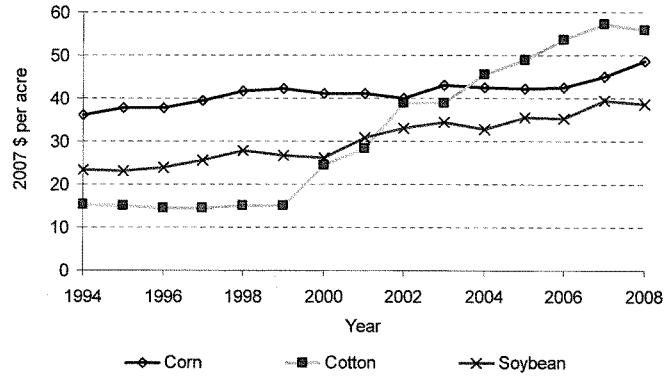


FIGURE 3-2 Estimated average seed costs for United States farmers in real (inflation-adjusted) terms.
SOURCE: Fernandez-Cornejo, 2004; USDA-NASS, 2000, 2005, 2009a.

The rise in real seed prices can be accounted for by improvements in germplasm, by the increasing price premiums paid for GE seed, and by the growing share of GE seed purchased by U.S. farmers (as the share of seed saved by farmers correspondingly decreased). The price premium, which includes the technology fee, doubled in real terms for GE cotton seed between

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2001 and 2007 (adjusted for inflation) (Figure 3-3). U.S. farmers also experienced similar price-premium increases for corn and soybean seed (Figure 3-4 and Figure 3-5). Some of the increase reflects the larger number of services that the seed delivers to the buyers compared with conventional seed. For example, farmers who purchase Bt cotton receive the seed germplasm and an insecticide combined in one product, whereas for non-GE crops they must buy each separately and pay for costs related to applying the insecticide. The increase also reflects the additional value to the farmer provided by later GE cultivars with more than one type of trait or more than one mode of action for particular target pests. The rates of adoption noted in Chapter 1 indicate that the price premiums have not deterred many U.S. farmers from purchasing GE seeds and that non-GE seed options were less attractive or were not available.

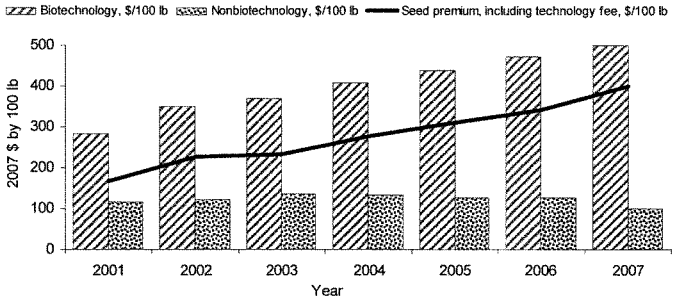


FIGURE 3-3 Real (inflation-adjusted) cotton seed prices paid by United States farmers, 2001–2007.
SOURCE: USDA-NASS, 2000, 2005, 2009a.

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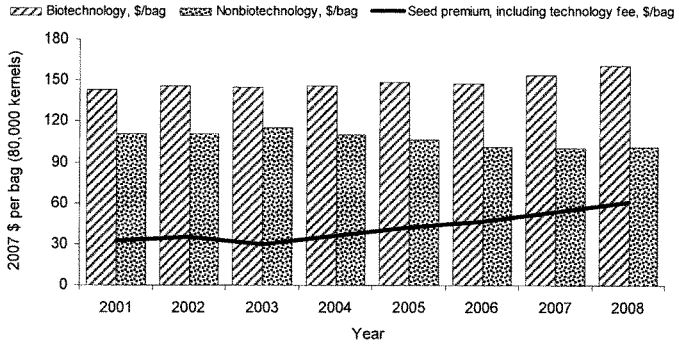


FIGURE 3-4 Real (inflation-adjusted) corn seed prices paid by United States farmers, 2001–2008.
SOURCE: USDA-NASS, 2000, 2005, 2009a.

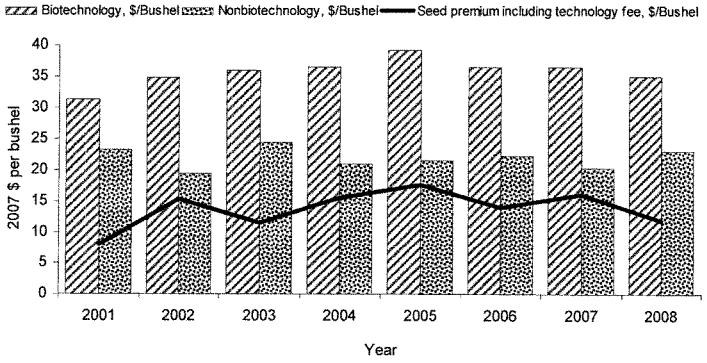


FIGURE 3-5 Real (inflation-adjusted) soybean seed price paid by United States farmers, 2001–2008.
SOURCE: USDA-NASS, 2000, 2005, 2009a.

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Other Input Costs

If U.S. farmers who have adopted GE crops pay higher prices for the seed, have they experienced compensatory cost reduction for other inputs? With insect-resistance technology, a plant contains its own insecticide, whereas most HR crops are engineered to be used with the herbicide glyphosate. Have those conditions changed adopters' farming practices and purchasing habits?

Economic reasoning suggests that the influence of genetic engineering on pesticide use depends on whether the GE cultivar and the pesticides are complementary or substitute inputs (Just and Hueth, 1993). Where IR or stacked GE cultivars substitute for other pesticides, chemical-pesticide use should decline. That is often the case with Bt crops (see Chapter 2, Figures 2-7 and 2-8). For HR crops, it often means reducing the use of less effective, more costly, and possibly more toxic herbicides although exceptions occur (Cattaneo et al., 2006). That substitution effect can produce cost savings as well as reductions in environmental and human health risks associated with chemical applications (Sydorovych and Marra, 2007). Several studies have attempted to establish whether the adoption of GE crops affects pesticide use. Some early investigations found evidence of a decline in pesticide use as adoption of GE crops increases (Heimlich et al., 2000; Hubbell et al., 2000; Carpenter et al., 2001; Marra et al., 2002). Some studies have found that most of the reduction in pesticide use resulting from adoption of an IR cultivar was in highly toxic chemicals, and average toxicity declined with adoption(Heimlich et al., 2000; Sydorovych and Marra, 2007). However, others have concluded that pesticide use increases in tandem with GE-crop production (Benbrook, 2004). Such contradictory findings have been attributed to the different approaches to measuring pesticide use, specifically

- How pesticide use is recorded (pesticide active-ingredient volume, formulated volume, relative toxicity, or number of applications) (Sydorovych and Marra, 2007).
- Which factors are controlled for (results would vary from region to region and from year to year depending on the extent of pest infestation, weather, cropping patterns, and so on).
- The method of aggregation (Frisvold and Marra, 2004).

A general overarching effect cannot be discerned because of the variability in specific conditions on different farms and in different regions.

The observed change in pesticide use with IR crops depends on the crop and the pest. Changes in insecticide use for treatment of European corn borer were minimal because many farmers accepted yield losses rather than incur the expense and uncertain results of chemical control. A survey of corn growers in Iowa and Minnesota determined that only 30 and 17 percent, respectively, had managed European corn borer with insecticides during any season in the early 1990s because chemical use was not always profitable and timely application was difficult owing to the unpredictability of pest outbreaks (Rice and Ostlie, 1997).

In the case of Bt cotton, however, GE control greatly reduced expenditures on pesticides to treat tobacco budworm, pink bollworm (*Pectinophora gossypiella*), and cotton bollworm (Jackson et al., 2003; Cattaneo et al., 2006). Survey data indicated that the number of insecticide sprays and insecticide costs generally decreased with the adoption of GE cotton across the United States (Table 3-1). Where measurable, farm-level profit was also shown to have increased with the adoption of Bt cotton in all states (Piggott and Marra, 2007). Although the studies

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reported in Table 3-1 seem to suggest that insecticide costs increased after commercialization of Bt cotton in Arizona, detailed surveys of insecticide use and costs conducted since 1979 clearly show that use and costs were drastically reduced after 1996 (Ellsworth et al., 2009). One major factor in the reductions has been the efficient control of the pink bollworm by Bt cotton (Carrière et al., 2003; Carrière et al., 2004). However, other critical factors in reducing insecticide use and cost were the introduction of novel and highly efficient insecticides for the control of the whitefly (*Bemisia tabaci*) in cotton (Carrière et al., 2004) and the success of the boll weevil eradication program (Fernandez-Cornejo et al., 2009). That illustrates an important point (see Chapter 2): longitudinal data on pesticide use should not be taken at face value in assessing the effects of GE crops without controlling for other influences, as many factors can contribute to changes in patterns of insecticide use.

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TABLE 3-1 Summary of Farm-Level Impact Evidence for Genetically Engineered Cotton in the United States, 1996–1999

	Differences in:															
	Yield					Pesticide Cost				Pesticide Use				Profit		
Transgene Type, State	Number of estimates	Mean	Minimum	Maximum		Number of estimates	Mean	Minimum	Maximum	Number of estimates	Mean	Minimum	Maximum	Number of estimates	Mean	Minimum	Maximum
	(count)	(pounds lint per acre)				(count)	(dollar/acre)			(count)	(sprays/acre)			(count)	(dollars/acre)		
Bt cotton																	
Alabama	4	143.5	231.5	38.0		2	–32.4	3.1	–68.0	2	–1.3	0.3	–3.0	2	77.6	116.5	38.7
Arizona	8	116.7	917.0	–331.5		9	17.1	97.0	–24.6	3	–2.2	–1.8	–2.5	10	57.5	465.0	–104.0
Georgia	3	75.2	104.0	38.0		3	–23.4	27.5	–68.0	3	–2.7	–2.5	–3.0	3	92.0	169.2	38.7
Louisiana	2	–7.5	22.0	–37.0		2	–20.0	–15.4	–24.6	2	–2.4	–2.2	–2.5	2	16.5	36.0	–3.1
Mississippi	8	22.6	92.0	–73.0		8	–5.1	13.8	–24.6	4	–2.4	–1.3	–3.3	6	34.5	79.5	–3.1
North Carolina	8	41.6	182.5	–35.7		2	–14.3	–1.2	–27.5	2	–2.4	–2.4	–2.5	8	20.5	95.1	–25.3
Oklahoma	4	168.0	203.0	123.0						4	–3.4	–2.3	–6.5	4	53.8	85.5	25.5
South Carolina	2	90.5	119.0	62.0		2	–16.2	–1.2	–31.1	2	–2.5	–2.5	–2.5	4	51.8	80.1	17.1
Tennessee	2	–79.0	85.0	–243.0		1	–5.6			1	–1.8			2	67.5	74.3	60.7
Texas	3	116.6	177.5	81.0										1	46.0		
Virginia	1	62.0				1	–1.2			1	–2.5			1	41.7		
BR cotton														1	17.1		
Arkansas	1	-150															
Tennessee	1	-243				1	-145.3							1	74.3		
Bt/BR cotton																	
Arkansas	2	292.8	–331.5	917.0		2	79.5	–269.0	159.0					2	243.0	21.0	465.0

SOURCE: Adapted from Marra, 2001.

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Bt corn is a preferred method for growers for controlling rootworm because of its simplicity and safety in applying it compared with soil-applied insecticides or with higher levels of active ingredient in seed treatments on non-Bt corn seed[10] (Al-Deeb and Wilde, 2005; Vaughn et al., 2005; Ahmad et al., 2006). The adoption of Bt corn for rootworm control has resulted in a substantial reduction in insecticide use, by an estimated 5.5 million pounds of active ingredient per 10 million acres (Rice, 2004).

In addition to the pesticide quantity effects, the adoption of HR and IR crops lowers the demand of competing pesticides used on conventional varieties and may therefore lower the prices of these pesticides. Huso and Wilson (2006) shows that this effect benefits farmers who adopt the GE variety and those who plant the conventional variety.

Indirect cost differences between GE crops and conventional crops originate in the adoption of practices that are linked to the adoption of some GE crops. For example, if a GE crop reduces the need for tillage to control weeds, reductions in machinery, fuel, and labor for the avoided cultivation practices amount to indirect cost savings. The indirect cost differences are particularly important for HR crops because of the complementary relationship between their adoption and conservation tillage. That is, GE-crop adoption increased the probability of adoption of conservation tillage, and conservation tillage increased the probability of higher adoption of GE crops (for a more detailed discussion of conservation tillage, see Chapter 2).

The increased use of conservation tillage has been facilitated by the commercialization of more effective postemergence herbicides, such as glyphosate, that can be applied topically to crops and weeds. Glyphosate can supplement or replace tillage as a tool for controlling most weeds and in so doing can reduce the use of machinery and fuel and lower labor requirements (Harman et al., 1985; Chase and Duffy, 1991; Baker et al., 1996; Downs and Hansen, 1998; Boyle, 2006; Baker et al., 2007). Mitchell et al. (2006) reported that a reduced-tillage system in the planting of California cotton reduced the number of tractors in operation by 41 to 53 percent, fuel use by 48 to 62 percent, and overall production costs by 14 to 18 percent. Sanders (2000) reviewed and summarized results of several studies and concluded that conservation tillage can reduce fuel costs by as much as 50 percent and labor cost by up to 40 percent. Those conclusions agree with USDA Natural Resources Conservation Service estimates that Iowa farmers would save 30-50 percent in fuel costs by adopting conservation-tillage practices (Table 3-2). Using Nebraska survey data for various row crops, Jasa (2000) showed that fuel use for no-till was 1.43 gal/acre compared with 5.28 gal/acre for moldboard-plow tillage and that labor requirements for no-till were 0.49 hours/acre, compared with 1.22 hours/acre for moldboard-plow use.

[10]As discussed in Chapter 1, Bt corn hybrid seed for corn rootworm control has 0.25 mg of active ingredient of insecticide and fungicide applied per seed compared to 1.25 mg of active ingredient applied to non-Bt corn hybrids.

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TABLE 3-2 Fuel Consumption by Tillage System (Gallons per Year)

Crop	Acres	Conventional Tillage	Mulch Till	Ridge Till	No-Till
Corn	1,000	4,980	3,710	3,330	2,770
Soybean	1,000	4,980	3,110	3,330	1,970
Total fuel use		9,960	6,820	6,660	4,740
Potential fuel savings over conventional tillage			3,140	3,300	5,220
Saving			32%	33%	52%

SOURCE: USDA-NRCS, 2008.

The financial returns to GE crops should vary directly with fuel prices if they save costly machinery passes over a field. HR crops do not necessarily save passes over a field, but they do substitute herbicide applications for more expensive and more fuel intensive methods of weed management, such as intensive tillage practices or the use of herbicides that require physical incorporation into the soil. Also, with potentially fewer passes over the field, tractor and spraying equipment lasts longer, and this results in savings in machinery and equipment costs over the long term.

Management Requirements and Nonpecuniary Benefits

Many of the commercially available GE products have consistently been shown to be profitable for U.S. farmers. For example, the profitability of Bt cotton in the Cotton Belt and Bt corn for controlling corn rootworm is well documented (Marra, 2001; Alston et al., 2002). However, the national evidence supporting the use of HR soybean is inconclusive (Bullock and Nitsi, 2001; Gardner and Nelson, 2007). Fernandez-Cornejo et al. (2002b) and Fernandez-Cornejo and McBride (2002) evaluated 1997 field-survey data and 1998 whole-farm survey data, respectively, and found that the differences in net returns between adopters and nonadopters of HR soybean were not significant. This lack of significance is consistent with findings from other producer surveys (Couvillion et al., 2000; Duffy, 2001). In light of high overall adoption rates, those findings suggest that other considerations have motivated farmers to use genetic-engineering technology. The wide adoption of HR soybean despite the associated technology fee stimulated research to identify possible nonpecuniary benefits to GE adopters that motivate such a shift in technology use.

In addition to the substantially superior control of a broad spectrum of weeds (Scursoni et al., 2006), simplicity, flexibility, and increased worker safety have been suggested as root causes of herbicide-resistance technology adoption, in that growers can use one herbicide instead of several to control a wide array of broadleaf and grass weeds (Gianessi and Carpenter, 1999; Bullock and Nitsi, 2001). The convenience of HR soybean use may mean that farmers can reduce the time that they spend scouting fields for weeds and mixing and spraying different

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herbicides to address various weed problems (Bullock and Nitsi, 2001). Furthermore, the window of application for glyphosate is wider than that for other postemergence herbicides. That application flexibility can effectively control weeds but often the weeds have already caused a loss in potential crop yield by the time glyphosate is applied.

However, quantifying the simplicity, flexibility, and safety of pest-control programs has been difficult. The inability to include a measure of management time in the evaluation of benefits of new technologies in agriculture is not unique to HR soybean. As Fernandez-Cornejo and Mishra (2007) observed, assessments of technology adoption using traditional economic tools pioneered by Griliches (1957) have proved insufficient to explain differing rates of adoption of many recent agricultural innovations. The standard measures of farm profits, such as net returns to management, give an incomplete picture of economic returns because they usually exclude the value of management time itself (Smith, 2002). HR soybean was adopted rapidly despite showing no statistically significant advantage in net returns over conventional soybean in most studies, but adoption of such strategies as integrated pest management has been rather slow even though it has explicit economic and environmental advantages (Fernandez-Cornejo and McBride, 2002; Smith, 2002). That inconsistency led to the hypothesis that HR adoption is driven by unquantifiable advantages—such as presumed simplicity, flexibility, and safety—that translate into a reduction in managerial intensity, which frees time for other pursuits, and into increased worker safety.

An obvious use of managers' time is off-farm employment; alternatively, a farmer could farm more acreage to increase farm income. Fernandez-Cornejo and collaborators examined the interaction of off-farm income-earning activities and adoption of different agricultural technologies of varied managerial intensity, including HR crops (Fernandez-Cornejo and Hendricks, 2003; Fernandez-Cornejo et al., 2005) and Bt corn (Fernandez-Cornejo and Gregory, 2004). They also estimated empirically the relationship between the adoption of those innovations and farm household income from on-farm and off-farm sources. To do that, they expanded the agricultural household model to include the technology-adoption decision and off-farm work-participation decisions by the operator and spouse (Fernandez-Cornejo et al., 2005; Fernandez-Cornejo and Mishra, 2007).

Those studies hypothesized that adoption of management-saving technologies frees operators' time for use elsewhere, most notably in off-farm employment, and that leads to higher off-farm income. They found that the relationship between the adoption of HR soybean and off-farm household income is positive and statistically significant: after controlling for other factors, a 15.9-percent increase in off-farm household income is associated with a 10-percent increase in the probability of adopting HR soybean. The adoption of HR soybean is also positively and significantly associated with total household income from off-farm and on-farm sources. A 9.7-percent increase in total household income is associated with a 10-percent increase in the probability of adopting HR soybean. In contrast, and consistent with the lack of higher returns from this technology, adoption of HR soybean did not have a significant relationship with household income from farming. Those findings complement the findings of Gardner and Nelson (2007), who used national survey data from 2001–2003 and found that adopting HR soybean reduced household labor requirements by 23 percent.

Studies have also found that farmers value the convenience and reduced labor requirements of Bt cotton above and beyond the pecuniary benefits. Because conventional cotton faces heavy pest pressure, IR varieties decrease the time demands of spraying, and this leads to a 29-percent reduction in household labor requirements (Gardner and Nelson, 2007). Survey data of Marra

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and Piggott (2006) support the finding that farmers place a monetary value on the convenience, flexibility, and relative safety of GE crops. In a stated-preference approach, participants in four surveys placed values on such characteristics as saved time, operator and worker safety, and total convenience. In each survey that evaluated the total-convenience attribute of genetic-engineering technology, it made up over 50 percent of the total value placed on nontraded aspects of the GE crop (Table 3-3). The median total value of convenience ranged from $3.33/acre per year for soybean to $5.00/acre per year for HR cotton. Survey respondents also placed a value on the improved operator and worker safety characteristics of GE crops. Farmers valued the reduction in handling and toxicity of the pesticides involved with those crops at $0.43–$2.36/acre per year. Although initially they increase the demand for GE seeds, the perceived management benefits may cause the demand for the seeds to become more inelastic (i.e., less responsive to price increases) over time. As farmers get accustomed to the characteristics and continue to place a value on them, increases in seed expenditures through either a price increase or an increase in user cost will not reduce the use of GE seeds by as large an amount as when the nonpecuniary attributes are not present (Piggott and Marra, 2008).

TABLE 3-3 Value and Relative Importance of Nonpecuniary Benefits to Farmers

	Re-scaled[a]			
	Median	Mean	Std Dev	Share
Characteristic			(%)	
Corn Rootworm Survey: n = 367				
Time saving	0.588	0.997	1.390	23.86
Equipment saving	0.400	0.724	0.969	17.51
Operator and worker safety	0.429	0.991	1.623	17.12
Environmental safety	0.208	0.787	1.565	10.88
More consistent stand	0.800	1.773	2.862	30.63
Sum of the parts	**3.000**	**5.272**	**6.222**	
National Soybean Survey: n = 113				
Operator and worker safety	0.913	1.660	2.026	20.97
Environmental safety	1.304	1.961	2.201	24.89
Total convenience	3.333	4.158	3.690	54.14
Sum of parts	**5.000**	**7.779**	**6.026**	

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North Carolina Herbicide-Resistant Crop Survey: n = 52				
Operator and worker safety	2.361	2.923	2.783	23.91
Environmental safety	1.666	2.720	2.660	20.45
Total convenience	5.000	7.793	7.818	55.63
Sum of parts	**10.000**	**13.437**	**10.612**	
Roundup Ready Flex Cotton Survey: n = 72				
Operator and worker safety	1.875	3.056	4.061	23.90
Environmental safety	0.958	2.592	3.382	18.06
Total convenience	5.000	11.180	15.441	58.04
Sum of parts	**10.000**	**16.828**	**17.383**	

[a]Rescaled to conform the magnitude of the overall value, which is asked as a separate question.
SOURCE: Marra and Piggott, 2006.

Management benefits do not appear to influence the adoption of GE corn. Fernandez-Cornejo and Gregory (2004) did not find a statistically significant relationship between adoption of Bt corn (to control corn borer) and off-farm household income, and Gardner and Nelson (2007) noted no effect of adoption of Bt or HR corn on household labor. The lack of a significant relationship supports the observation that most farmers accepted yield losses rather than incur the expense and uncertainty of chemical control for European corn borer before the introduction of Bt corn (Fernandez-Cornejo et al., 2002a). For those farmers, the use of Bt corn was reported to result in yield gains rather than pesticide-related savings, and savings in managerial time were small. However, one of the benefits of adoption of Bt corn for rootworm control is that it makes it unnecessary to handle toxic insecticides at planting or to deal with high rates of insecticide-treated seeds.

Thus, the econometric results are consistent with anecdotal statements that many GE crops save managerial time because of the associated simplicity and flexibility of pest control. In the case of some GE crops, such as HR soybean, these nonpecuniary benefits provide incentives for adoption that counteract the additional cost of GE seeds. Indeed, the benefits increase demand for the GE seeds, and that in turn supports a higher price. In the case of other GE crops, such as Bt cotton, nonpecuniary benefits are accrued above and beyond additional farm profits.

Lower management costs and increased yield and nonpecuniary benefits have figured in the economic value of the natural refuge for cotton with two endotoxins for control of the bollworm-budworm complex. As discussed in Chapter 2, the Environmental Protection Agency (EPA) changed the refuge requirement for these IR cotton varieties from a 20 percent refuge treated with insecticide (or a 5 percent refuge not treated with insecticides) to a natural refuge where wild host plants constitute the refuges. The benefits of the refuge change were estimated for North Carolina to be $26.90 per year per impacted acre when pecuniary and nonpecuniary impacts were considered (Piggott and Marra, 2007).

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Value and Market-Access Effects

In addition to the input-cost effects, the use of GE crops can affect the revenue potential of farmers. Two such effects can occur: foreign yield effects on the prices of products sold and market access to sell the GE crops.

Increase in grain and oilseed supplies should result in downward pressure on the prices received by farmers, all else being equal. Genetic-engineering technology helped to boost yields that had already been growing over the last 70 years through improved plant-breeding techniques. As a result, supply exceeded demand; the real price of food (adjusted for inflation) had fallen until 2006. However, over the period 2006–2008, corn and soybean prices increased rapidly because of various factors, including the rise in world incomes and the demand for renewable fuels made from agricultural feedstock. The increase in the global supply of those crops due to the adoption of GE crops and improvements in germplasm and plant breeding likely moderated the upward pressures on prices during this time.

Assessing the impact of new agricultural technologies on commodity prices is difficult because the effect on price cannot be measured directly. As Price et al. (2003) explain, once a new technology is introduced and adopted, only the world price that results from increasing global supply (supply shift) can be observed. It is not possible to observe the counterfactual price—the price that would have existed, assuming the same supply and demand conditions, if the new technology had not been introduced (see Box 3-1). Therefore, the counterfactual world prices and demanded quantities of the commodities must be estimated from market equilibrium conditions by using econometric models, which generally are reliable in the short term and when systems are stable.

The approach to calculating the effect of genetic-engineering technology on commodity prices followed by most studies (Falck-Zepeda et al., 2000a; Falck-Zepeda et al., 2000b; Moschini et al., 2000; Price et al., 2003; Qaim and Traxler, 2005) is based on the theoretical framework developed by Moschini and Lapan (1997) to assess the impacts of an innovation on economic welfare when the innovator behaves as a monopolist under the protection of intellectual-property rights in an input market by pricing the new technology above marginal cost (the cost of producing one more unit of a good) (Price et al., 2003). Changes in the economic welfare of producers and consumers in a competitive output market can also be measured because some of the benefits generated by the innovation are passed on to them in the form of higher production efficiency and lower commodity prices.[11]

Table 3-4 shows the estimates of the effect of GE-crop adoption (corn, soybean, and cotton) on crop prices. The price effects are different for each crop and technology and depend on the market penetration (the extent of adoption) of the new technology and on the details of the

[11] As Price et al. (2003) described it, the estimated total market benefit of adopting each of the GE crops depends on the extent to which the global commodity supply curve shifts outward after the introduction of the technology. In each case, the shift in supply reflects potential yield increases and/or decreases in costs. The estimated market benefit also depends on the interaction of the supply and demand curves before and after the introduction of the new technology. The empirical models calculate the preinnovation and postinnovation prices and quantities in an international market setting by using information on adoption rates, crop yields, costs, technology fees, and seed premiums. The framework also takes into account the adoption of biotechnology outside the United States. The counterfactual world price, the equilibrium world price without the innovation, is the sum of the observed market price and the vertical supply shift resulting from the adoption of GE crops. The equilibrium world price occurs at the intersection of the excess-supply and excess-demand curves.

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models used (particularly supply and demand parameters). For example, adoption of Bt cotton was associated with a decline in cotton prices of 0.65 percent for the first year of adoption in the United States only but with a price decline of 1.1 percent when adoption continued in the United States and took place in other countries. The effect of adoption of HR soybean varieties on soybean price ranged from a decline of 0.17 percent in 1997, when adoption had only occurred in the United States, to about 2-percent decline following further adoption in the United States and Argentina and a 2.6-percent decline for world adoption in 2001. Simultaneous adoption of Bt corn and HR soybean could lead to a decline in corn prices of 2.5 percent and a decline in oilseed prices of 3.9 percent, all other things being equal.

Table 3-5 presents the estimated distribution of the tangible benefits among consumers, farmers, technology providers (biotechnology firms), seed firms, and consumers and producers in the United States and the rest of the world. The distribution of benefits varies by crop and technology because the economic incentives to farmers (crop prices and production costs), the payments to technology providers and seed firms, and the effect of the technology on world crop prices are different for each crop and technology. For example, farmer adoption of HR cotton benefits mainly consumers, whereas adoption of Bt cotton benefits farmers and technology providers. Innovators (technology providers and seed firms) are often the largest beneficiaries in the case of HR soybean, but producers and consumers also gain (Moschini et al., 2000). The aggregate net benefits to crop farmers depend on the aggregate cost saving relative to the estimated price decreases and increased production (sales). The lower output prices may deter some farmers who have relatively lower yield gains or higher costs from adoption. But farmers with sufficient yield gains and cost saving will adopt GE crops even when an increase in supply puts downward pressure on prices. Livestock producers primarily receive benefits from lower prices of feedstocks than would have occurred without GE-crop adoption. Analyses of the benefits of GE crops and their distribution have many nuances.

The studies mentioned above analyzed the economic effects of GE varieties during the early period of their adoption of these technologies (the latest study used data from 2001).[12] Results of studies of adoption in agriculture (Feder et al., 1985) suggest that early adopters of new yield-increasing technologies gain early in the life of the technologies, but that their gains dissipate as prices go down. The United States was the dominant early adopter of GE varieties; James (2009) has since found a high rate of adoption of GE varieties more recently, mostly in developing countries. The agricultural products produced with genetic engineering are traded globally, and adoption of GE varieties worldwide affects prices that U.S. farmers receive.

[12]These studies were carried out before Brazil began producing large amounts of GE soybean. The entry of Brazil into the GE soybean market and the continued expansion of GE soybean in Argentina may have pushed considerable amounts of the benefits from producers to consumers.

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TABLE 3-4 Effect of Global Adoption of Genetically Engineered Crops on Commodity Prices

Technology and Crop	Adopting Areas	Commodity Name	Price Decline	References
Bt cotton	United States (first year)	Cotton	0.65%	Falck-Zepeda et al., 2000b
Bt cotton	United States, other producing countries[a]	Cotton	1.11%	Price et al., 2003
HR cotton	United States	Cotton	3.4%	Price et al. ,2003
HR soybean	United States	Soybeans	0.17%	Price et al. , 2003
HR soybean	United States	Soybeans	1.0%	Moschini et al., 2000
HR soybean	United States, South America	Soybeans	2.2%	Moschini et al., 2000
HR soybean	World	Soybeans	2.6%	Moschini et al. , 2000
HR soybean	United States, Argentina	Soybeans	1.96%[c]	Qaim and Traxler, 2005
HR soybean and canola, Bt corn[b]	United States, Canada, Argentina	Oilseeds	2.9%	Anderson and Jackson, 2005
HR soybean and canola, Bt corn[b]	United States, Canada, Argentina	Corn	1.94%	Anderson and Jackson , 2005
HR soybean and canola, Bt corn[b]	World	Oilseeds	3.08%	Anderson and Jackson, 2005
HR soybean and canola, Bt corn[b]	World	Corn	2.09%	Anderson and Jackson, 2005
Bt corn, HR soybean	United States Canada	Oilseeds	1.5%	Fernandez-Cornejo et al., 2007
Bt corn, HR soybean	United States Canada	Corn	2.5%	Fernandez-Cornejo et al., 2007
Bt corn, HR soybean	World	Oilseeds	3.87%	Fernandez-Cornejo et al., 2007

[a]Assumes that countries other than the United States would have a 50 percent efficiency of technology transfer. Adoption is for 1997.
[b]Adoption rates assumptions vary by country and crop. See details in Anderson and Jackson (2005).
[c]Price decline reported is for 2001. Qaim and Traxler (2005) also calculated price declines for other years; for example, 1.54 percent for 2000 and 1.25 percent for 1999.

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According to (James, 2009), 331 million acres of land were planted to GE cultivars worldwide in 2009, of which nearly 95 percent was in six countries: the United States, Argentina, Brazil, Canada, India, and China. The total global acreage planted to GE crops in 2009 amounted to 8 percent of the world's tillable cropland. The GE cultivars were mostly of four crops: soybean (52 percent), corn (31 percent), cotton (12 percent), and canola (5 percent). In 2009, 77 percent of the soybean area, 49 percent of the cotton, 26 percent of the corn, and 21 percent of the canola lands were grown with GE cultivars. Much of the adoption of GE corn and cotton has been in the United States, Argentina, and Brazil, but China and India are major adopters of Bt cotton. The majority of acres planted to GE crops were HR varieties, at approximately 62 percent, followed by stacked traits at 21 percent and IR varieties at 15 percent. Stacked traits grew at a 23 percent rate from 2007 to 2008, the highest rate of the three trait categories (James, 2009).

According to Sexton et al. (2009), the high increases in yield that resulted from adoption of Bt cotton in developing countries have contributed to the increase in the world cotton supply and to the relatively low prices of cotton from 1998–2008. They suggest that the decline in the price of cotton relative to the price of other agricultural commodities has contributed to the transition from cotton to other crops in California. The same shift away from cotton is taking place in other cotton-producing regions. Total upland cotton-planted acreage in the United States has declined by 36.8 percent since 2002 (USDA-NASS, 2009).

Soybean acreage began to increase in the United States in 1997 and stayed relatively high until 2002, in part because the commodity support prices in the Federal Agricultural Improvement and Reform Act of 1996 favored soybean over other program crops. Even though Sexton et al. (2009) found that average yield of soybean—the crop with the highest rate of adoption of GE cultivars—grew more slowly than that of cotton after the introduction of GE varieties, the introduction of GE soybean contributed to the expansion of harvested soybean area worldwide, which grew by nearly 30 percent from 1997 to 2007 (FAO, 2008). In Argentina alone, GE soybean enabled adoption of no-till practices, which facilitated double cropping of wheat and soybean and contributed to a 9.9-million-acre increase in the soybean area from 1996 to 2003 (Trigo and Cap, 2003). The adoption of GE soybean in South America contributed to the increase in soybean supply, which also occurred because of the expansion of soybean acreage in Brazil. That supply shift caused downward pressure in soybean prices and had an adverse effect on growers in the United States, although the price effect was overwhelmed by the effect of increased global demand for soybean during the period 2006–2008.

Many of the analyses summarized in Table 3-4 and Table 3-5 are based on partial-equilibrium models (in which the price of one good is examined and all other prices are held constant), but several studies have examined the effect of adoption of GE cultivars on producers and consumers by using a computable general-equilibrium approach (the prices of good are examined in relationship to one another). Some of the studies also attempted to assess the costs of access barriers imposed on GE crops by the European Union (EU), which has had a moratorium on the production and import of GE crops since 1999. Qaim (2009) has surveyed those studies and found that they predict an annual global welfare gain to consumers and producers from adoption of GE cultivars without restrictions, ranging from $1.4 billion from the adoption of Bt cotton to $10 billion from the adoption of GE oilseed and corn. The results of the studies suggest that bans on imports of GE crops reduce the potential economic welfare of several parties, including U.S. farmers, but that European consumers suffer much of the loss.

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TABLE 3-5 Adoption of Genetically Engineered Crops and Their Distribution

Study	Year	Total Benefits ($ million)	Share of Total Benefits (%)			
			U.S. farmers	Innovators	U.S. consumers	Net RoW
Bt cotton						
Falck-Zepeda et al., 1999	1996	134	43	47	6	
Falck-Zepeda et al., 2000a	1996	240	59	26	9	6
Falck-Zepeda et al., 2000b	1997	190	43	44	7	6
Falck-Zepeda et al., 1999	1998	213	46	43	7	4
Frisvold et al., 2002	1996–1998	131–164	5-6	46	33	18
US-EPA, 2001[a]	1996–1999	16–46	NA	NA	NA	NA
Price et al., 2003	1997	210	29	35	14	22
Herbicide-resistant cotton						
Price et al., 2003	1997	232	4	6	57	33
Herbicide-resistant soybean						
Falck-Zepeda et al., 2000b	1997-LE[b]	1,100	77	10	4	9
	1997-HE[c]	437	29	18	17	28
Moschini et al., 2000	1999	804	20	45	10	26
Price et al., 2003	1997	310	20	68	5	6
Qaim and Traxler, 2005	1997	206	16[d]	49	35	NA[e]
Qaim and Traxler, 2005	2001	1230	13[d]	34	53	NA[e]

Note: NA = not applicable; RoW = rest of the world (includes consumers and producers).
[a]Limited to United States farmers.
[b]LE = low elasticity; assumes a United States soybean supply elasticity of 0.22.
[c]HE = high elasticity; assumes a United States soybean supply elasticity of 0.92.
[d]Include all soybean producers.
[e]Included in consumers and producers.
SOURCE: Fernandez-Cornejo and Caswell, 2006, Qaim and Traxler, 2005.

Anderson and Jackson (2003) estimated that even under free trade—with global welfare gain from the introduction of GE cultivars of cotton, corn, and oilseed that will enhance supply—farmers in the exporting countries will actually lose 0.07 percent of their income because of lower prices, whereas low-income consumers in North America will stand to gain from the introduction of GE cultivars because of lower food prices, all other things being equal. A moratorium on the export of GE crops to the EU will quadruple the losses to U.S. farmers. Such asynchronous conditions, when GE crops are approved at different times or not at all by different countries, could influence farmers' planting decisions because of those losses. Yet at the same time that U.S. farmers suffer economically, U.S. consumers benefit. A more severe moratorium on GE exports by the EU and other developed economies, such as that of Japan, is estimated to reduce the income of North American farmers by 0.5 percent. Those bans will hurt European consumers but benefit European farmers. Nielsen and Anderson (2001) showed that the welfare

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costs of less drastic barriers, such as labeling and segregation requirements, are important but smaller than the cost of bans.

Lence and collaborators (Lence and Hayes, 2005a, b; Lence and Hayes, 2006; Lence et al., 2005) show that, in addition to the cost saving and other benefits, the overall welfare impact of genetic-engineering technology depends on the level of consumer concern with the technology and the costs of identity preservation. In particular, they state that their results suggest "the United States may have maximized welfare by not requiring labeling" of GE corn and soybean, but they claim that their results also suggest that "recently approved EU legislation enforcing labeling of GE crops also makes sense because consumer concern in the EU appears to be greater than that in the United States."[13]

The literature suggests that adoption of GE cultivars puts downward pressure on crop prices and increases the earnings of adopting farmers in the early years of the adoption process and that barriers to access reduce grower income. But there is a paucity of studies of the welfare effects of genetic-engineering technology in recent years, when adoption has increased globally, and this is an important subject for future research.

ECONOMIC IMPACTS ON OTHER PRODUCERS

Livestock Producers

Much of the soybean and corn produced in the United States is fed to livestock (Figure 3-6 and 3-7), and byproducts are used in consumer products, so quality and nutritional characteristics of soybean and corn associated with GE crops have been closely examined. Most studies of soybean have reported no differences in animal performance (Hammond et al., 1996); in important nutritional qualities, such as isoflavones (Duke et al., 2003); or in other characteristics at the macroscopic level of HR soybeans (Magaña-Gómez and Calderón de la Barca, 2009). Researchers (Cox and Cherney, 2001; Jung and Sheaffer, 2004) have reported that glyphosate-resistant Bt corn does not affect feeding-quality characteristics of corn silage. Lutz et al. (2006) reported that the Bt protein Cry1Ab is degraded during the ensiling process. In feeding studies, there was no difference in milk production or milk composition between glyphosate-resistant corn, with or without the stacked Bt gene, and nontransgenic hybrids (Barrière et al., 2001; Phipps et al., 2005; Calsamiglla et al., 2007). There were no differences in body weight and feed use between rats fed grain from a Bt corn rootworm hybrid and rats fed grain from a nontransgenic hybrid (He et al., 2008). Likewise, no differences were observed in mortality, weight gain, feed efficiency, or carcass yield between broiler chickens fed grain from a Bt corn rootworm hybrid and chickens fed grain from a near-isoline (McNaughton et al., 2007). Thus, empirical studies have clearly indicated that there is no adverse effect on quality of livestock feed or on the output or quality of livestock products.

[13]The welfare implications of different regimes of protection of intellectual property rights in the seed industry have also been studied (Lence et al., 2005).

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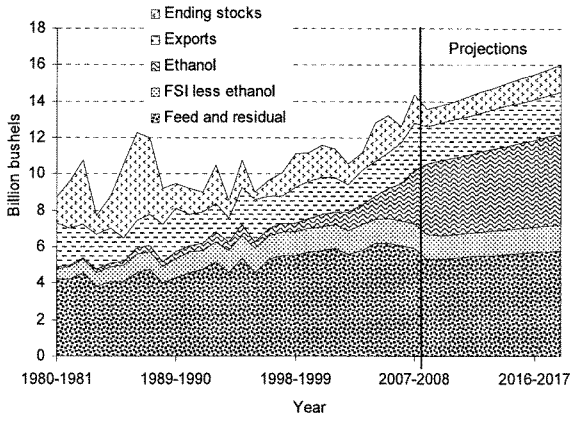


FIGURE 3-6 United States corn use.
NOTE: FSI = food, seed, and industrial.
SOURCE: USDA-ERS, 2009.

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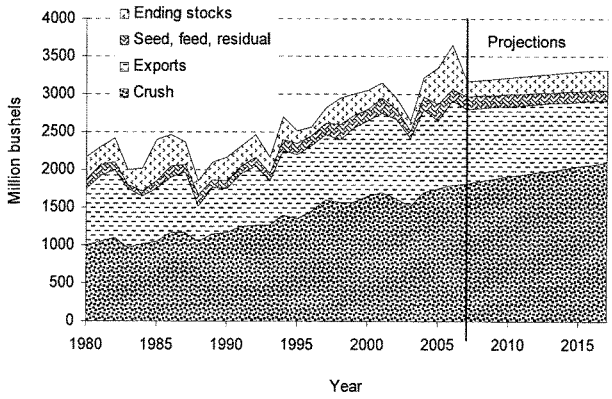


FIGURE 3-7 United States soybean use.
Note: Crush is used primarily for livestock feed.
SOURCE: USDA-ERS, 2009.

Furthermore, nutritional characteristics of GE and conventional corn hybrids—including fatty acid profiles, mineral and vitamin contents, lutein, and total phenol and antioxidant activity—were comparable (Venneria et al., 2008) although some slight differences in triglycerides and urinary phosphorus and sodium extractions were noted in male rats (Magaña-Gómez and Calderón de la Barca, 2009). Cotton seed is used as a byproduct in animal feed, and cottonseed oil is used for human consumption. Castillo et al. (2004) found that Bt cotton seeds were deemed nutritionally equivalent with no difference in feed intake, milk yield, or composition. Few studies have been conducted to assess the levels of the glyphosate metabolite aminomethylphosphonic acid (AMPA) in glyphosate-treated, glyphosate-resistant corn hybrids; however, one study by Reddy et al. (2008) reported no detection of AMPA. Duke et al. (2003) reported that AMPA was detected in glyphosate-treated, glyphosate-resistant soybean seeds; however EPA has not established a tolerance for AMPA. Given that AMPA is not considered significantly toxic (Giesy et al., 2000), the discovery of AMPA in glyphosate-treated, glyphosate-resistant soybean is not considered to be an issue of importance at this time.

Feed costs constitute nearly half the variable costs of livestock production, so even moderate price fluctuations can seriously affect the trajectory of the livestock market (USDA-NASS, 2008). As mentioned above, livestock operators are the buyers of feed, and they are the major beneficiaries of reductions in the prices of corn and soybean, to which the adoption of GE crops has contributed. They also benefit from increased feed safety from the reduction of mycotoxins (Wu, 2006). We are not aware of any quantitative estimation of savings to livestock operators and final consumers due to the adoption of GE crops or of the resulting effect on the profitability of livestock operations. This is another subject on which future research is desirable.

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Producers of Non-Genetically Engineered Crops

The adoption of GE crops affects production costs for non-GE farmers in several key ways. GE crops alter the demand for inputs, and this affects the cost of inputs to GE and non-GE crops alike.[14] For example, Bt crop varieties that reduce insecticide use also lower the input costs for producers who use insecticides that substitute for Bt because the lower overall demand for them puts downward pressure on their prices. In other cases, GE crops increase the demand for other inputs. HR varieties increase demand for broad-spectrum herbicides, like glyphosate, which can have mixed effects on the price. On the one hand, the increase in demand puts upward pressure on the prices of those herbicides and, everything else being equal, increases the profits of the firms that manufacture GE seeds. On the other hand, the expanded market for broad-spectrum herbicides compatible with HR crops may allow firms to reduce the price of the herbicide but still increase profits through greater sales. HR varieties also affect the demand and prices for the herbicides that were used before HR crop varieties became available, usually by lowering prices because of reduced demand.

We have observed in Chapter 2 that GE crops can affect production of non-GE crops favorably or unfavorably through externalities associated with pest-control activities. To the extent that genetic-engineering technology successfully reduces pest pressure on a field, farmers of adjacent or nearby fields planted with non-GE crops may benefit from reductions in costs for pest control associated with reductions in regional pest populations (Sexton et al., 2007). Such favorable externalities may exist for Bt crops, which control pests that target GE and non-GE crops equally (Ando and Khanna, 2000). HR crops may provide some benefits to non-GE crops on adjacent fields by reducing rates of pollination of weeds, but more certain benefits will accrue to crops planted in rotation with GE crops. Specifically, because HR crops permit the postemergent use of broad-spectrum herbicides, such as glyphosate, weed species that affect GE and non-GE crops may be controlled more effectively. In particular, glyphosate has proved effective in controlling perennial weeds that appear late in the principal crop season, persist, and impose losses on subsequent crops (Padgette et al., 1996; Shaw and Arnold, 2002). The reduction in pest pressure from the late-season use of effective chemicals on HR crops may benefit the crop planted in the following season (Baylis, 2000; Tingle and Chandler, 2004) although empirical evidence of this effect is scarce. A massive field trial of crop rotation and herbicide application practices in Britain has provided evidence that the production systems used for HR canola can improve weed control in cereal crops planted in rotation (Sweet et al., 2004).

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[14] As stated above, the introduction of GE crops will probably reduce pest damage and, in some cases, will reduce the commodity prices of corn, soybean, and cotton. In the damage-control framework, the demand for inputs other than the ones controlling pests (such as water and energy) is represented by (Lichtenberg and Zilberman, 1986)

$$\text{Quantity demanded} = (\text{crop price})(1 - \text{damage})(\text{marginal value of the input in producing potential output}).$$

This equation suggests that GE cultivars will contribute to increased demand for inputs—such as fertilizer, water, and capital—if adoption of GE cultivars increases the earning per unit of potential output, which is equal to (crop price)(1 – damage), assuming no acreage constraints. Thus, when the introduction of GE cultivars does not affect crop prices but reduces pest damage, adoption of GE crops increases the demand for other input use. That increases the demands for fertilizer, water, capital, and so on, and causes upward pressure on their market prices. When the introduction of GE cultivars reduces commodity prices substantially, it may lead to reduced demand for other inputs. We are not familiar with empirical studies that have tried to estimate the impact of GE crops on the demand for or prices of other inputs, and this is a subject for future work.

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Farmers of non-GE crops may also experience adverse externalities associated with HR-crop weed control. Growers experience an adverse effect when an economically important amount of herbicide resistance builds up. As discussed in Chapter 2, resistance to broad-spectrum herbicides is a concern associated with adoption of HR varieties because use of other chemicals drastically declines in favor of the herbicide to which the crop is resistant (Shaner, 2000). When resistance in weeds evolves, farmers have resorted to managing those weeds with additional forms of control; they have either increased their use of the herbicide to which the HR crops are resistant, used additional and possibly more expensive forms of weed control (such as cultivation), or both. Such actions not only reduce or reverse the environmental benefits of HR crops reviewed in the previous chapter but also result in higher production costs for the grower compared to using glyphosate alone. To date, costs have not risen to the level of costs incurred in the conventional systems of weed control. If they had, a substantial reduction in the use of HR crops would have occurred. Resistance-management strategies, such as the use of refuges, can be expensive for individual farmers, though such strategies can provide long-run pest control benefits in the area that will offset the sum of individual costs if implemented correctly. Although Bt crops may be prone to resistance buildup because the toxins that target pests are always present in the field, the refuge requirements for Bt crops have thus far provided adequate protection from insect resistance buildup in the United States. The tradeoff is the requirement to plant some percentage of a crop to non-Bt cultivars, which may result in net economic costs to producers growing IR crops. Those costs, if they occur, are in the form of higher pesticide costs, foregone yield, or both. A benefit is the lower cost of seed for the refuge acres. A case in point is Bt cotton with the single trait for bollworm and budworm control, for which EPA requires a 20 percent insect-treated refuge or a 5 percent non–insect-treated refuge in the Southeast. Farmers who choose the 20 percent refuge can incur higher insecticide costs to treat insect infestations—more passes over the field and more labor to scout for insects—but have lower overall seed costs. Those who choose the 5 percent, untreated refuge can experience substantial yield loss on the refuge acres, though the cost of seed for those acres is lower. It is important to note that before the introduction of the Bt crops substantial insect resistance to other classes of insecticides, such as pyrethroids, had been observed.

SOCIOECONOMIC IMPACTS OF GENE FLOW

Inadvertent gene flow from GE to non-GE crops can also have a variety of social and economic effects. Both the Ecological Society of America and the National Research Council have recognized that some degree of gene flow between sexually compatible GE and non-GE crops occurs regularly (NRC, 2004; Snow et al., 2005). Indeed, the presence of adventitious GE traits in the intended non-GE seed supply of canola, cotton, corn, and soybean and in the seed supply of GE crops (e.g., a Bt trait in crop seed that is intended as HR only) is well documented (Beckie et al., 2003; Friesen et al., 2003; Mellon and Rissler, 2004; Heuberger et al., 2008; Heuberger and Carrière, 2009) The probability of gene flow is similar in both directions between GE and non-GE varieties of a crop (Mallory-Smith and Zapiola, 2008); however, for farmers, consumers, and food distributors, the actual and perceived consequences of gene flow from GE to non-GE crops are greater than the consequences of gene flow from non-GE to GE crops.

Gene flow between GE and non-GE crops occurs via three routes: cross-pollination between GE and non-GE plants from different fields (as discussed in "Gene Flow and Genetically Engineered Crops" in Chapter 2), co-mingling of seed before the production year (in the

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presence of GE traits in seed bags of non-GE crops) or during the production year (mixing of seed at planting, at harvest, or during storage), and germination of seeds left behind (i.e., volunteers) after the production year (Owen, 2005; McHughen, 2006). Generally, GE and non-GE crops can coexist. However, given that some domestic and foreign consumers are willing to pay a premium for non-GE products, there are strong market incentives as well as some sociocultural reasons for farmers, seed distributors, and food processors to minimize the adventitious presence of GE traits in non-GE crops and derived products (Lin et al., 2003; Belcher et al., 2005; Furtan et al., 2007; Devos et al., 2008).

Gene flow between HR and non-HR crops can increase production costs if gene flow promotes weediness. For example, when volunteer seeds survive and germinate to the following season, field management costs increase because the volunteers will not be eliminated by glyphosate applications. Similarly, if HR traits cross into weedy relatives, weed-control expenses will be higher for all fields on to which these weeds spread, whether the farmer grows GE crops or not (Smyth et al., 2002).

Gene flow of GE traits could jeopardize the economic value of the entire harvest of non-GE-crop farmers by rendering their output unsuitable for high-value markets (Bullock and Desquilbet, 2002). They could also have unfavorable effects on the levels of trust that exist between market participants. Two groups of farmers could be impacted by gene flow: those farming non-GE crops conventionally and organic farmers. The U.S. government does not have thresholds for what level of purity is required to characterize a product as non-GE; the thresholds are instead determined by the market. The U.S. National Organic Program excludes GE methods from the organic process (OFPA, 2009). Because of adventitious gene flow, the organic process does not necessarily result in a non-GE product when it goes to market; whether adventitious presence is discovered depends on if testing for GE material is conducted. Therefore, if GE traits are discovered in organic crops intended for a non-GE market, the organic or non-GE status of a crop may be forfeited depending on the potential legal or market tolerances for the presence of GE traits (Gealy et al., 2007). Other governments have set thresholds for organic and non-GE crops; for example, Japan has a 5 percent threshold for corn while the EU has zero tolerance for non-approved GE material but a 0.9 percent permissible level for GE material that has been approved by the EU (Bradford, 2006; Ronald and Fouche, 2006). Tests can be performed to assess the presence of GE traits in grain to preserve the identity of non-GE grain; whether a positive test results in rejection of a product depends on the individual policies of buyers. Additional research is needed to determine the extent to which screening is used and its relationship to variation in consumer desires for purity in the food supply. Although non-GE products can lose market value because of the adventitious presence of GE material, the price of GE products is not affected by the adventitious presence of non-GE material. Accordingly, gene flow between GE and non-GE crops imposes costs primarily on consumers and producers of GE-free crops (Smyth et al., 2002; Belcher et al., 2005; Devos et al., 2008). Such a need to protect the market value of non-GE products probably contributed to the creation of GE-free zones in some regions of the United States and in the EU (Jank et al., 2006; Furtan et al., 2007). Widespread use of GE crops in the United States may have forced some corporations that were producing GE-free products to move their operations to countries where GE crops were less prevalent (Mellon and Rissler, 2004). Nevertheless, a survey published in 2004 suggested that 92 percent of U.S. organic growers who responded to the survey had not incurred any direct costs or suffered losses attributable to the adventitious presence of GE crops (Brookes and Barfoot, 2004). However, it must be noted that there have been considerable increases in the adoption of

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GE crops in the United States as well as growth in U.S. organic-crop production and the market for non-GE products since this survey was conducted, that so far GE traits have been incorporated into a small number of crops that have few near-relatives in U.S. agriculture, and that few studies have analyzed trends in the socioeconomic impacts of gene flow.

A zero tolerance for the presence of GE traits in non-GE crops is generally impossible to manage and is not technically or economically feasible. Pollen transfer between sexually-compatible GE and non-GE crops is difficult, if not impossible, to prevent, and segregation between GE and non-GE products may be accomplished more easily and economically when nonzero thresholds for the adventitious presence of GE material in non-GE end-user products and seed are established. The goal of the thresholds is to set acceptable limits for the presence of GE traits that have been deemed safe and approved for human consumption. Accordingly, programs aimed at establishing such thresholds are analogous to seed-certification and food-labeling programs that have been used for decades to ensure the quality of seeds for agriculture and of food for consumers. The difficulty of maintaining the coexistence of GE and non-GE crops increases as the tolerance for the adventitious presence of GE traits in non-GE products becomes lower and the adventitious presence of GE traits in non-GE products becomes easier to detect even at very low levels due to technological advances.

The situation has a drastically greater impact when GE traits *not* approved for human consumption contaminate non-GE products. Such contamination can have strong adverse effects on market value, on the possibility of exporting crops, on the costs of remedial actions to remove contaminated supplies, and therefore on the profit margins of food producers and distributors (Lin et al., 2003; Vermij, 2006; Vogel, 2006). It can also undermine public confidence in the food system. The effects of the identification of a variety of Bt corn marketed under the name StarLink® in human food constitute an important example. StarLink® was approved only for use in animal feed but was discovered in products destined for human consumption. The resulting concerns about food safety led to the recall of more than 300 food products, and some major U.S. export markets, such as Japan and South Korea, imposed trade restrictions (Lin et al., 2003). The technology developer ultimately discontinued sale of StarLink® seed. Similarly, the accidental release of glufosinate-resistant rice in the United States in 2006 and the contamination of sulfonylurea-resistant flax in Canadian exports in 2009 imposed heavy costs on farmers, commodity traders, and processors.

Those examples of accidental releases, or any other low-level presence of unapproved GE material in the food supply, impose considerable costs on the food system that need to be accounted for in cost-benefit analyses of GE crops (Salazar et al., 2006). They also affect farmers' planting decisions because of the risk of lost revenues and other economic and social costs. As more exotic GE crops (e.g., pharmaceuticals) enter the commercialization phase, possible supply disruptions will multiply with greater potential for conflict between sectors in the food and non-food industries and substantial economic costs. Such potential market and political repercussions indicate that a very low tolerance threshold set by U.S. regulatory authorities is appropriate for the presence of unapproved GE traits in food intended for human consumption.

Certain groups of consumers prefer GE-free products, a preference that is likely to increase the demand for products made with ingredients from organically grown crops. The NOP regulations require the certified organic producers must produce and handle their organic agricultural products without the use of GE methods (NOP, 1990). However, the unintentional presence of GE material in organic products will not necessarily lead certifying agents to change the status of an organic product or operation (Federal Register, 2000). As explained above,

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because some level of gene flow between GE and non-GE crops is difficult to prevent, the adventitious presence of GE material has been detected in non-GE products, including certified organic products. Therefore, the process-based NOP standard that excludes GE methods in production and handling systems does not assure that organically grown crops with non-GE methods will be free of GE material for marketing.

The presence of GE material can affect the ability of growers to sell non-GE and organic crops in domestic and foreign markets with requirements beyond the process-based standard of the NOP. Accordingly, policies have been established to manage the potential for adventitious presence while enabling coexistence of GE, GE-free, and organic production systems. However, policy-established tolerance thresholds for the adventitious presences of traits from commercialized GE crops in non-GE or organic products vary considerably among countries. For example, in the United States, voluntary labeling of food as GE-free is allowed as long as a product contains less than 5 percent adventitious presence of GE material(Demont and Devos, 2008; OFPA, 2009). In contrast, the EU allows up to 0.9 percent adventitious GE material in non-GE food, animal feed, and products labeled as organic if the GE crop has been approved in the EU; otherwise, the threshold is zero (Demont and Devos, 2008). Certified non-GE seed sold to farmers in the United States is typically expected to contain less than 0.5-1 percent of seeds (depending on crop type) with GE traits (Mellon and Rissler, 2004; CCIA, 2007). Thresholds for commercial seed have been considered but have not yet been implemented uniformly in the EU (Kalaitzandonakes and Magnier, 2004; Devos et al., 2008).

GE-free or organic products lose their premium market value when the adventitious presence of GE material exceeds established government or market thresholds. Anecdotal stories suggest that the crops of U.S. organic growers are being screened in the marketing chain for the presence of GE material and are being rejected if levels exceed market-determined levels. We do not have evidence to judge how widespread such testing is in the United States. This issue deserves more investigation to determine the extent of such market-led behavior and the social and other factors driving it. We do know that given the threshold criteria in the EU for GE material in organic products, food produced in the United States and labeled as organic by U.S. certifiers could be rejected in the EU as not organic because of adventitious presence of GE material even though no GE seed or crops were used in production by U.S. producers. The coexistence of GE and non-GE products is possible as long as measures are taken to ensure that the adventitious presence of GE traits remains below the thresholds set in receiving markets, either by governments or buyers. In general, threshold differences among regions contribute to creating barriers to the use of GE crops and trade in non-GE products (Smyth et al., 2002; Demont and Devos, 2008; Devos et al., 2008).

Separating GE and non-GE products at every step of the production process is expensive, and costs increase as thresholds for the presence of GE traits in non-GE products decrease (Lin et al., 2003; Kalaitzandonakes and Magnier, 2004). Growers must attend to details and apply considerable effort to achieve effective segregation between GE and non-GE crops (CBI, 2007). Grain segregation in normal production settings is difficult but can be accomplished and could effectively minimize the co-mingling of GE and non-GE crops. Given that co-mingling of seeds can be costly for growers, particularly for growers who have specific contracts that restrict GE traits, tactics for isolating GE crops from non-GE crops must be established effectively (Owen, 2000). Controlling volunteer GE crops in non-GE crops may not be difficult, depending on crop rotation, but requires considerable diligence on the part of growers (Owen, 2005). When volunteer crops acquire a GE trait for herbicide resistance via unintended gene flow, weed-

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management costs for a grower may increase and potential crop yield may decline if the crop planted the following season is also resistant to glyphosate (Owen and Zelaya, 2005). Furthermore, the isolation distances required to maintain complete segregation for open-pollinated crops are often too large to be economically feasible (Matus-Cádiz et al., 2004).

An economic assessment based on data from major seed firms in the United States indicated that reducing the adventitious presence of GE traits in non-GE corn seed from 1 percent to 0.3 percent would raise seed production costs by about 35 percent (Kalaitzandonakes and Magnier, 2004).[15] The increased costs would involve changes in field operations and in processing and result from new expenses for extra purity testing, storage, and transportation, but most of the increase in production costs would result from measures taken at the field level to minimize gene flow. Thus, programs that set levels of tolerance for the adventitious presence of GE traits in non-GE products probably have substantial impacts on growers directly and would increase the cost of non-GE seed and the market value of GE-free and organic products (Smyth et al., 2002; Kalaitzandonakes and Magnier, 2004; Belcher et al., 2005).

Barring the risk of contamination, GE crops can contribute to the creation of market opportunities for non-GE farmers. The organic market is a primary example. By virtue of the ban on the use of GE traits in the official USDA definition of organic production, the organic movement can market itself to, and collect a price premium from, consumers who prefer not to purchase food or fiber produced with genetic-engineering technology. Consumer preference for non-GE foods may be related to other traits associated with organic production, but the stated price premium for non-GE crops is substantial in some segments of the population (Huffman et al., 2003).

CONCLUSIONS

The widespread adoption of GE crops has had agronomic and economic implications for adopters and non-GE producers in the United States. For GE farmers, the general increase in yield, reduction in some input costs, improvement in pest control, increase in personal safety, and time-management benefits have generally outweighed the additional costs of GE seed. The use of HR crops has not greatly increased yields, but it has generally improved weed control, especially on farms where substantial weed resistance to the specific herbicide to which the HR crop is resistant has not developed, and it has improved farmers' incomes by saving time thus facilitating more off-farm work or providing more management time on the farm. IR crops have increased yields in areas where economically damaging insect-pest pressures occur and have saved on expenditures for conventional pesticide. Thus, the use of HR and IR crops has mostly increased adopters' incomes compared with the use of non-GE varieties.

It should be noted that the economic benefits have changed over time and probably will continue to change. Yield lag and yield drag were not uncommon when HR crop varieties were first introduced, but GE traits have since been incorporated into high-yielding varieties, and improved GE events have replaced the initial events. Although research has identified those changes in farmers' experience with GE crops, there has been little investigation of the economic impact of GE crops more recently. More research would improve the information available to

[15]This study is a summary assessment over various GE crop technologies and therefore should not be applied to specific situations. It is likely that the impacts would vary considerably over different GE cultivars and their specific farming situations.

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farmers, plant breeders, and policy-makers as market, environmental, and social conditions change.

The extent to which GE crops make it economical to expand production to lands not previously cultivated or to intensify production on existing cropland with double cropping has not been reported adequately in the literature. More research on the economic effects of GE-crop adoption on non–GE-crop producers would also be beneficial. Examples include the costs and benefits of shifts in pest management for non-GE producers due to the adoption of GE crops, the value of market opportunities afforded to organic farmers by defining their products as non-GE crops, the economic impacts of GE adoption on livestock producers, and the costs to farmers, marketers, and processors of adventitious presence or contamination from approved or unapproved GE traits and crops into restricted markets.

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4

Farm-System Dynamics and Social Impacts of Genetic Engineering

The dissemination of genetically-engineered (GE) crops, like the adoption process associated with other farm-level technologies, is a dynamic process that both affects and is affected by the social networks that farmers have with each other, with other actors in the commodity chain, and with the broader community in which farm households reside. As noted in Chapter 1, farmer decisions to adopt a technology are influenced not only by human-capital factors, such as the educational level of the adopter, but by social-capital factors, such as access to information provided by other farmers through social networks (Kaup, 2008). That necessarily implies that farmers receive information from others—for example, on the risks and benefits of a particular technology—and that they share their own knowledge and experience through the same networks. Such findings confirm the relevance of social factors in influencing how genetic-engineering technology is adopted, what the impacts of its adoption are, and the significance of farmers' active participation in both formal and informal social networks with other actors in commodity chains and communities.

However, little research has been conducted on the social impacts of the adoption of genetic-engineering technology by farmers, even though there is substantial evidence that technological developments in agriculture affect social structures and relationships (Van Es et al., 1988; Buttel et al., 1990). Because further innovations through genetic engineering are anticipated, such research is needed to inform seed developers, policymakers, and farmers about potential favorable benefits for adopters and nonadopters and unwanted or potentially unforeseen social effects (Guehlstorf, 2008). With such information, the likelihood of maximizing social benefits while minimizing socials costs is increased. To demonstrate the necessity for increasing commitments to the conducts of research on the social effects of GE-crop adoption, this chapter synthesizes what is known in the scientific literature about the social impacts of farm-technology adoption and the interactions between farmers' social networks. The chapter also identifies future research needs.

SOCIAL IMPACTS OF ON-FARM TECHNOLOGY ADOPTION

The earliest academic research in the United States on the social impacts of technology adoption at the farm and community levels was focused on mechanical technologies. More than a century ago, the use of machines in U.S. agriculture not only displaced labor but widened

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socioeconomic discrepancies between skilled and unskilled laborers (Quaintance, 1984). Academic interest in the socioeconomic consequences of agricultural mechanization was particularly strong in the 1930s and 1940s in the southern United States (Buttel et al., 1990) and again in the 1970s throughout the country. Berardi (1981) summarized the findings of the literature and found that mechanization was associated with decreases in the agricultural labor force, particularly those among the least educated and least skilled workers and in minority groups; with better working conditions and less "drudgery" for the remaining work force; with a decrease in farm numbers and an increase in farm size; with increased capital costs for agricultural producers; and with a decline in the socioeconomic viability of agriculture-dependent rural communities. Data also suggested that the technological development of U.S. agriculture had contributed to declines in farm labor, in community dependence on agriculture, and in rural community viability although other on-farm and off-farm factors also contributed to these changes (Van Es et al., 1988).

In the 1980s, social scientists broadened their research on the impacts of technology adoption on farms and farm communities to include studies of the potential and actual impacts of biological (pre–genetic engineering) technologies in agriculture. Many observers assumed that, unlike the earlier wave of mechanical agricultural technologies, genetic-engineering technology would not be biased towards large-scale farming operations. Such an assumption was supported by analyses of the production capabilities of agricultural biotechnology. For example, it was noted that no interaction effect was observed between genetic predisposition to produce milk and the use of the growth hormone bovine somatotropin (BST) to increase milk production in dairy cows (Nytes et al., 1990). However, other studies that directly examined farm-level social change revealed that, despite the presumption of scale-neutrality, it was difficult to isolate the impacts of biological innovations from those of other technological innovations in agriculture because biological innovations were often developed and disseminated in conjunction with other technologies that may not have been scale-neutral (Kloppenburg, 1984).

Additional research conducted on the social impacts of biotechnology in animal agriculture, specifically on the use of BST, noted that rates of adoption of BST were moderate and that, although adoption did not require large herds, scale effects were observed because BST use was more effective in high-producing cows, which were more likely to be found in large herds with complementary feeding technologies (Barham et al., 2004). Beck and Gong (1994) also observed the existence of a scale effect with adoption of BST, with adopters more likely to have larger herds, as well as being younger and having more formal education. Additionally, it was suggested that the quality of farm management had an impact on the benefits accruing to the adoption of BST (Bauman, 1992). The use of BST also was thought to lead to lower prices and thus to result in increased economic pressure on smaller producers (Marion and Wills, 1990). In other words, the body of research on the socioeconomic consequences of the use of biotechnologies, including Green Revolution technologies, indicated that "scale neutrality is not inevitable, but a possibility that depends on institutional context" (DuPuis and Geisler, 1988: 410). To put it another way, the social context of the adoption process and the impacts on that context are interconnected, from which it follows that the social impacts of genetic-engineering technology on farms and communities differ among cultures, commodities, and historical periods.

Thus, though seed varieties are generally conceptualized as being scale-neutral, the adoption of any technology may be biased toward large firms that can spread the fixed costs of learning over greater quantities of production (Caswell et al., 1994). In developing countries, the

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economics of genetic-engineering technology do not appear to vary with farm size (Thirtle et al., 2003). However, scale may affect accessibility to technology. Small farmers have less influence in input supply and marketing chains with which to secure access to desired technologies. Thus, there can be a scale bias in the development and dissemination processes associated with herbicide-resistance technology that puts small farmers at a disadvantage. In contrast, as noted in Chapter 3, insect-resistance technology can replace insecticide applications that require fixed capital investments, such as for tractors and sprayers. In this regard genetic-engineering technology has the potential to favor small farmers, who would benefit more from a technology that required less fixed capital investment. The scale effects of transgenic varieties may also depend on the pricing (such as quantity discounts) set by seed companies, which typically assess a technology-user fee.[1]

An early empirical study was carried out by Fernandez-Cornejo et al. (2001) using 1998 U.S. farm data. They found that, as expected, the adoption of HR soybean was invariant to size, but adoption of HR corn was positively related to size. They explained this disparity as due to the different adoption rates: 34 percent of the farms had adopted HR soybean at the time, implying that adoption of HR soybean had progressed passed innovator and early-adopter stages into the realm where adopting farmers are much like the majority of farmers. On the other hand, adoption of HR corn was quite low at the time (5 percent of farms), implying that adoption was largely confined to innovators and other early adopters who in general tend to control substantial resources and who are willing to take the risks associated with trying new ideas. Thus, they claimed that the impact of farm size on adoption is highest at the very early stages of the diffusion of an innovation (HR corn), and becomes less important as diffusion increases. This result confirms Rogers's (2003) observations that adoption is more responsive to farm size at the innovator stage, and the effect of farm size in adoption generally diminishes as diffusion progresses. Early adopters, by virtue of early adoption, also are able to capture a greater percentage of the economic benefits of the technology adoption process.

Clearly, one cannot extrapolate the social impacts of the adoption of GE crops based solely on an assumption that the productive capabilities of genetic-engineering technology, when isolated from the interaction with other factors, should be scale-neutral. In other works, previous research on the social impacts of agricultural technologies suggests the possibility that the early dissemination of genetic-engineering technology would be associated with farm size, and that the use of GE crops could have differential impacts across farm types, farm size, and region, despite the fact that GE crops are presumed to be scale-neutral.

In an article that attempted to predict some of the environmental, economic, and social effects of genetic engineering of crops, it was argued that the use of GE crops was "clearly capable of causing major ecological, economic, and social changes" (Pimentel et al., 1989 p. 611). Nonetheless, over the last decade, there has been virtually no empirical research conducted on the social impacts of the use of GE crops on farms and rural communities. The lack of research may have to do in part with the scarcity of funds available for such research as well as a relative lack of interest in social issues on the part of environmental groups (Chen and Buttel, 2000), and other groups and organizations that might be expected to support such research. Nonetheless, the results of research referred to above on the social repercussions of agricultural technologies, including non–genetic-engineering biotechnology in crops and biotechnology in

[1]Examples of empirical studies on the effect of farm size on GE adoption are given in "An Early Portrait of Farmers who Adopt Genetically Engineered Crops" in Chapter 1.

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animal agriculture, would suggest that there are impacts, that these impacts could be favorable or adverse, and that adverse impacts could be alleviated through the adoption of appropriate policies. For example, based on earlier research on the introduction of new technologies in agriculture, it might be hypothesized that certain categories of farmers (those with less access to credit, those with fewer social connections to university and private sector researchers, etc.) might be less able to access or benefit from existing GE crops. There is also the possibility that the types of genetic advances being marketed do not meet the needs of certain classes of farmers, and that the full spectrum of the potential of genetic-engineering technology is not being achieved. Furthermore, the possibility exists that communities where farmers play an important social, political, and economic role could be impacted as well. However, for the purpose of this report, no conclusion on the social impacts of the adoption of GE crops can be drawn on the basis of empirical evidence. Research on such impacts clearly should be accorded a high priority as genetic-engineering technology evolves. Without such research, the potential for genetic-engineering technology to contribute to the sustainable development of U.S. agriculture and rural communities cannot be adequately assessed. Thus, we recommend that such research be sponsored and pursued actively and immediately.

SOCIAL NETWORKS AND ADOPTION DECISIONS

The adoption of genetic-engineering technology and its performance on the farm are functions of the knowledge of agricultural decision-makers, who include farmers, input suppliers, commodity traders, farm-management consultants, and extension agents. In making technology-adoption decisions, farmers rely principally on information about the relative performance of competing technologies and on information about best practices for optimizing yields and controlling costs, given the technologies that they use. The performances of firms and technology, therefore, depend upon the information used by various commodity-system actors. Just et al. (2002) have shown that the internal competences of decision-makers affect the degree to which they rely on different types and sources of information.

Farmers rely on a variety of intermediaries—such as extension agents, commodity groups, commercial vendors, agricultural media, and other farmers—for information. For example, farmers often turn to commodity associations for information about regulations and regulatory changes. Many of the intermediaries that farmers communicate with use public information, especially data and research results provided by the U.S. Department of Agriculture (USDA) Economic Research Service and the National Agricultural Statistics Service and by state extension services, particularly for information about the economic outlook of agriculture and specific industries. Intermediaries use formal channels of information more than farmers (Just et al., 2002) and then make that information available to farmers.

Farmers obtain about half their information from informal sources (i.e., sources whose professional duties do not include provision of information) (Just et al., 2002), including people in the end-users' civic, community, professional, and commercial networks, like neighbors, colleagues, customers, and suppliers. Farmers' reliance on informal sources may reflect low availability of or access to information from formal channels, issues of affordability of private information, and credibility (Just et al., 2002).

Those findings suggest that farmers' attitudes toward GE crops are likely to be affected by a number of information providers. USDA's Cooperative Extension Service, commodity groups, and agricultural media are particularly influential in informing farmers' views on the technical

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aspects of genetic-engineering technology, its economic implications, and its prospects. Although the influence of those sources has not been widely appreciated, they have played a key role in the adoption of the technology. As Wolf et al. (2001) and Just et al. (2002) demonstrated, informal sources of information are just as likely as formal sources to accelerate or to slow the rate of GE-crop adoption. It would also be reasonable to hypothesize that patterns of information use would be linked to the ability of farmers to use the technology effectively and maximize its potential.

INTERACTION OF THE STRUCTURE OF THE SEED INDUSTRY AND FARMER DECISIONS

The U.S. seed industry has experienced extensive structural change in the last few decades. The changes have affected decisions at the farm level by shaping the choices available to corn, soybean, and cotton farmers.

As Fernandez-Cornejo and Just (2007) have summarized, plant-breeding research until the 1930s was conducted primarily by the public sector (for example, USDA and state agricultural experiment stations), and most commercial seed suppliers were small, family-owned businesses that multiplied seed varieties that had been developed in the public domain. Seeds embody the scientific knowledge needed to produce a new plant variety with desirable attributes—such as higher yield, disease or pesticide resistance, or improved quality—so seed innovators face both the risk of imitation by competing seed firms and the risk of seed reproduction by farmers themselves (Fernandez-Cornejo, 2004). The development of hybrid corn in the first half of the 20th century provided breeders with greater protection of intellectual-property rights (IPR) because seeds saved post-harvests produced substantially smaller yields than the hybrid plants from which they were gathered. With that incentive, the number of private firms engaged in corn breeding grew rapidly.

The proliferation of firms was followed by consolidation in part because U.S. law evolved to provide incentives to innovators for research and development by giving them exclusive control of their innovations through patent laws and other forms of enforceable legal protection (Fernandez-Cornejo, 2004). Two principal forms of legal protection for seed innovators are plant variety protection (PVP) certificates issued by the Plant Variety Protection Office of USDA and patents issued by the Patent and Trademark Office (PTO) of the U.S. Department of Commerce. Both grant private crop breeders exclusive rights to multiply and market their newly developed varieties. Patents provide more control because PVP certificates have a research exemption that allows others to borrow a new variety for research purposes (Fernandez-Cornejo and Schimmelpfennig, 2004). IPRs for seed innovators were strengthened by the U.S. Supreme Court's 1980 *Diamond* v *Chakrabarty* decision, which extended patent rights to GE microorganisms, important tools and products of biotechnology. A series of rulings by PTO's Board of Appeals and Interferences widened the scope of patent protection for GE organisms by including plants and nonhuman animals. Those rulings extended IPRs to a wide array of new biotechnology products in the form of utility patents (also referred to as patents for invention). Products protected under the rulings include seeds, plants, plant parts, genes, traits, and biotechnology processes (Fuglie et al., 1996; Fernandez-Cornejo, 2004).

Enhanced IPR protection has brought rapid increases in private research and development (R&D), and indirectly assisted technology developers in setting prices above marginal costs (Goldsmith, 2001). Private spending on R&D in crop varieties increased by a factor of 14 in real

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terms from 1960 to 1996 (Fernandez-Cornejo, 2004), whereas public (federal and state) spending changed little (Figure 4-1); (Fernandez-Cornejo and Schimmelpfennig, 2004). At the same time, IPR protection may have spurred market concentration in the seed industry. The potential profits of seed firms made possible through IPR protection may strengthen the incentive to invest and thus provide greater opportunities to large firms (Lesser, 1998). Many seed firms have been acquired by corporations that have the resources needed to achieve large economies of scale in R&D (Fernandez-Cornejo, 2004). For example, Lesser (1998) stated that more than 50 seed firms were acquired by pharmaceutical, petrochemical, and food firms after the passage of the Plant Variety Protection Act.[2] In contrast, Lesser (1998) also noted that weakness of IPR protection may lead to mergers and acquisitions. In any case, by 1997, the share of U.S. seed sales controlled by the four largest firms reached 69 percent for corn (up from 60 percent 1973), 47 percent for soybean (up from 7 percent in 1980), and 92 percent for cotton (up from 74 percent in 1970) (Table 4-1; Fernandez-Cornejo, 2004). Though it is difficult to obtain recent detailed published market share information, it appears from company reports and other sources that the trend of increased concentration in the structure of the seed industry continued in recent years.[3] Farm survey data for corn and soybean indicated that by 2007 the share of the four largest firms reached 72 percent for corn and 55 percent for soybean (Figure 4-2; Shi and Chavas, 2009).

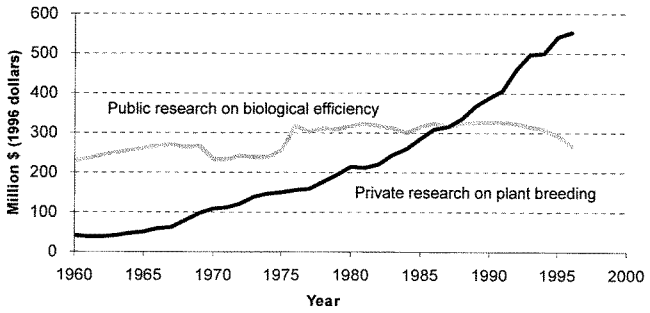


FIGURE 4-1 Public and private research expenditures on plant breeding. Biological efficiency includes breeding and selection of improved plant varieties.
SOURCE: Fernandez-Cornejo, 2004.

[2]The Plant Variety Protection Act (PVPA) of 1970 granted plant breeders a certificate of protection that gave them exclusive rights to market a new plant variety for 18 years from the date of issuance. Amendment of the PVPA in 1994 brought it into conformity with international standards. Protection provided by certificates of protection was extended from 18 to 20 years for most crops (Fernandez-Cornejo, 2004).

[3]In the case of corn, Pioneer has lost its dominant position in the corn seed market from about 40 percent to 30 percent while Monsanto's share of the corn seed market increased to about 30 percent as a result of the Landec acquisition (Leonard, 2006).

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TABLE 4-1 Estimated Seed Sales and Shares of Major Field Crops, United States, 1997

Company	Total ($ billions, current)	Corn Market Share	Soybean Market Share	Cotton Market Share
		Percentage of Acres		
Pioneer Hi-Bred International	1.18	42.0	19.0	—
Monsanto/Stoneville	0.54	14.0	19.0	11.0
Novartis/Syngenta	0.26	9.0	5.0	—
Delta & Pine Land	0.08	—	—	73.0
Dow Agrosciences/Mycogen	0.14	4.0	4.0	—
Golden Harvest	0.09	4.0	—	—
AgrEvo/Cargill	0.09	4.0	—	—
Others	1.12	23.0	53.0	16.0
Total	3.50	100.0	100.0	100.0

SOURCES: Hayenga, 1998; Fernandez-Cornejo, 2004.

Concentration of R&D output can also be used to measure the concentration in innovation activity in the seed industry (Fulton and Giannakas, 2001). In genetic-engineering technology, a measure of R&D output is the number of GE cultivars approved by USDA for release into the environment for field testing. In particular, Fernandez-Cornejo (2004) adapted the four-firm concentration-ratio measure, commonly used to quantify industry concentration in terms of sales, to examine R&D concentration on the basis of regulatory approvals of GE crop varieties. Table 4-2 shows the percentage of field releases obtained by the leading four firms in 1990–2000. The top four firms controlled well over 50 percent of the approvals; this suggests consolidation in R&D and potential barriers to entry for competitors. As Fulton and Giannakas (2001) noted, expenditures on R&D and expenditures made to obtain regulatory approvals are sunk costs—costs that cannot be recouped. If such sunk costs are present, markets are not contestable, so there are potential barriers to entry.[4]

[4]A contestable market behaves in a competitive manner despite having few companies because of the threat of new entrants.

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TABLE 4-2 Four-Firm Concentration Ratio in Field-Release Approvals from USDA Animal and Plant Health Inspection Service, by Crop, 1990–2000

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Corn	67	67	65	82	82	67	60	73	73	80	79
Soybeans	100	100	94	68	72	94	82	82	71	87	85
Cotton	100	100	100	89	79	85	91	64	98	98	96

SOURCE: Fernandez-Cornejo, 2004.

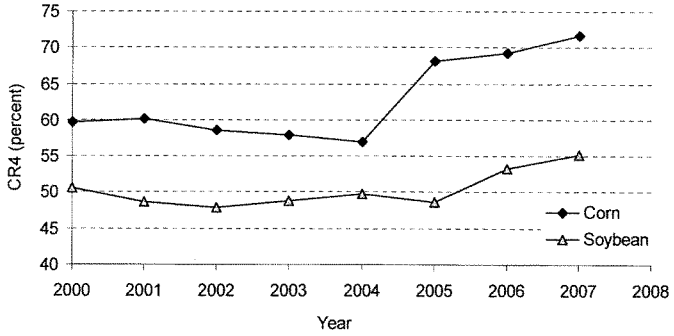


FIGURE 4-2 Share of planted acres of corn and soybean seeds by largest four firms (CR4). SOURCE: Stiegert et al., 2009.

As Fernandez-Cornejo (2004) observed, on the basis of the four-firm concentration ratio of approvals, the extent of corn-seed R&D concentration has been relatively constant at around 72 percent, which is fairly consistent with the four-firm concentration ratio in corn in terms of sales. Cotton-seed R&D is the most centralized, and this is also consistent with market-concentration measures.

Patent ownership shows a pattern of concentration similar to that evident in other R&D measures (Fernandez-Cornejo, 2004). Most of the biotechnology patents awarded to private firms are held by a small number of large companies. As of 1996–1997, Pioneer (soon after DuPont/Pioneer) held the largest number of patents for corn and soybean, followed by Monsanto (Brennan et al., 2000). The leading firms in the sector have received IPR protection not only by virtue of their respective R&D investments but through mergers and acquisitions. For example, Pioneer was one of the first four companies active in the emerging corn-seed market in the early 1930s. As shown in Figure 4-3, Pioneer (Pioneer Hi-Bred International, Inc.) made a series of

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acquisitions in 1973–1980 that strengthened its overall position in the seed market. The chemical firm DuPont bought 20 percent of Pioneer in August 1997 and bought the remaining 80 percent in 1999 for $7.7 billion. As a DuPont company, Pioneer continues to operate under the Pioneer name and remains headquartered in Iowa (Fernandez-Cornejo, 2004).

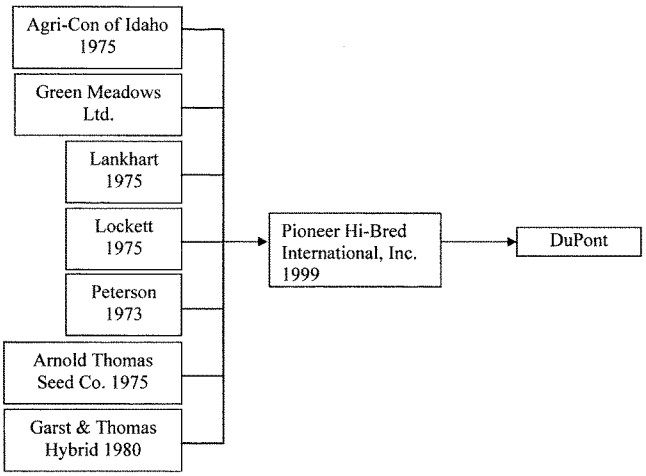


FIGURE 4-3 Evolution of Pioneer Hi-Bred International, Inc. / E. I. du Pont de Nemours and Company.

SOURCE: Fernandez-Cornejo, 2004.

Although the increase in seed-industry concentration has raised concerns about its potential impact on market power, and ultimately on the sustainability of farms, empirical results for U.S. cotton and corn seed industries over the period covering 1970–1998 (which includes only 2 years of GE-crop adoption) suggest that increased concentration during that time period resulted in a cost-reducing effect that prevailed over the effect of enhanced market power (Fernandez-Cornejo, 2004). Goldsmith (2001) argued that even though GE-seed prices were above the competitive price, the actions of biotechnology supply firms apparently were not adversely affecting the welfare of U.S. farmers.

However, concerns have been raised that, in time, such market power could lead to decreased variability in the types of seeds being produced for the market, as well as increased prices, which could limit the ability of farmers to purchase those seeds most suited for local environmental conditions. In addition, it is conceivable that the continued market power of biotechnology supply firms could lead to increased input costs for farmers, which in turn could have an unfavorable effect on the socioeconomic sustainability of farms. A recent study by Shi and

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Chavas (2009) has found that vertical integration (ownership of control of different stages of production) in the U.S. soybean seed industry had a substantial effect on soybean prices. Shi et al. (2008) analyzed the pricing of corn seed with stacked traits for the years 2000–2007 and found "significant departures from component pricing (where seeds are priced as the sum of their component values). The evidence supports sub-additive pricing. It shows that the marginal contribution of each component to the seed price declines with the number of components." The authors also have indicated that "such a finding is consistent with the presence of economies of scope in seed production. Indeed, synergies in R&D investment (treated as fixed cost) across seed types can contribute to reducing total cost."

In response to these concerns and others, USDA and the U.S. Department of Justice launched a series of workshops in 2010 to examine competition and regulatory issues in the agriculture industry (USDA, 2010). This is a first step towards updating and continuing research on how market structure in the seed industry may be impacting seed prices and availability to variability in genetic resources. In addition, studies of how seed-industry concentration, as well as the practice of cross-licensing, could interact with farmers' planting options and decisions, overall yield benefits, crop genetic diversity, and economic returns would be very valuable.

Although the private sector owns the majority of agricultural-biotechnology patents, the public sector still owns a substantial share. In a study of assignment of U.S. plant-biotechnology patents granted from 1982 to 2001, Graff et al. (2003) found that 41 percent of the patents were owned by large biotechnology companies, 35 percent by startups, and 24 percent by the public sector. The public-sector ownership is weaker in some categories, such as Bt and other insect-resistant traits (10 percent) and plant enzymes (8 percent), but stronger in other categories (42 percent in flowering and 56 percent in pathogen resistance). The capacity of the public sector to obtain freedom to operate in transgenic crops is often also constrained by the fragmentation of technology ownership among numerous institutions. Improved access to information about IPRs and reduced transaction costs to obtain rights to use patents could increase the public sector's contribution to the development of transgenic varieties. Concerns have also been raised that technology use and stewardship agreements prevent scientists in the public sector from conducting independent assessments of GE varieties marketed by the private sector. In February 2009, in response to a notice in the *Federal Register* on a meeting of the Federal Insecticide, Fungicide, and Rodenticide Act Scientific Advisory Panel, 26 entomologists submitted a general comment that, because of those restrictions, the data that the Environmental Protection Agency received regarding GE crops were inherently limited (*Federal Register*, 2009). If such restrictions exist, farmer welfare could be adversely affected by the lack of complete information regarding GE traits or crops. However, the degree to which technology use agreements may hamper public research is unclear and strongly disputed by private-sector seed companies (Monsanto, 2010). This issue merits careful investigation by neutral researchers to understand what, if any, effects such agreements have on public research.

SOCIAL AND INFORMATION NETWORKS BETWEEN FARMERS AND INDUSTRY

Agriculture is unique among American industries in that federal law allows farmers to cooperate in some collective activities while competing in the output market. That has enabled farmers to act collectively as a counterweight to the large firms on which they rely to sell their output (Cochrane, 1993). Farmers have developed cooperatives to coordinate research and marketing efforts to benefit from economies of scale in these activities (Sexton, 1986). That

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collective-action capacity is important for adoption of genetic-engineering technology in that it gives farmers the ability to influence crop traits that are introduced.

Farmers may attempt to block seed technologies if they anticipate that those new technologies will not enhance, or perhaps even endanger, farm profit. Innovation in any crop can increase farm revenue if the elasticity of demand for the crop is sufficiently high that increases in output compensate for decreases in prices. But if the elasticity of demand is low, increased output may lead to a fall in revenue and a decrease in profit unless the technology delivers cost savings. In the latter case, farmers may attempt to block the introduction of a technology. Farmers may also block a technology if its introduction would result in lower prices in national or international markets.

A large body of literature on the political economy of research argues that farmers use political pressure to shape public research funding. Ruttan (1982) argued that farmer pressure may have led to underinvestment in public research in the United States, and deGorter and Zilberman (1990) linked overall spending on research to the political power of such groups as consumers and producers. Graff and Zilberman (2007) argued that farmers' interests partly motivated Europe's effective ban on GE crops, which in turn affected the access of U.S. farmers who were growing GE crops to European markets.

Another example of farmers' collective action is how farmers' concerns influenced Monsanto's decision to halt its efforts to introduce and market herbicide-resistant (HR) wheat. Some farmer coalitions in the United States and in Canada played a role in that decision because they feared losing access to European and Asian markets that would not accept HR wheat. It was thought that the introduction of that GE crop might have closed markets to U.S. and Canadian farmers who planted non-GE wheat because of the difficulty in segregating wheat on fields and in grain elevators and trucks (e.g., Chin, 2004; Pollack, 2004). Many international buyers, including millers and bakers in important Asian and European markets, had made it clear that they wanted to purchase identity preserved (IP), non-GE commodities (Vandenberg et al., 2000). In the case of white wheat, Japan and South Korea, two countries that have GE-food labeling laws, were importing more than one-fourth of U.S. white wheat exports (Squires, 2004). Japanese millers and bakers were well aware that a large percentage of Japanese consumers were expressing negative attitudes toward the use of genetic-engineering technology in foods and believed that their government's regulation of GE food was too lax (Toyama et al., 2001). Indeed, Japan was the United States's largest market for non-GE corn and soybean: nearly 90 percent of the IP, non-GE corn and soybean produced in the United States was being exported to Japan (Wilson et al., 2003). Faced with such demands from the marketplace and with farmer concern about how those demands might influence sales in those markets, Monsanto decided to defer the introduction of HR wheat in 2004.

However, farm organizations are not monolithic; indeed, the issue of HR wheat divided the farming community (Graham and Martin, 2004). Even after Monsanto chose to suspend its HR-wheat program, wheat producers and support groups, such as the National Association of Wheat Growers, exhibited a strong interest in glyphosate-resistant wheat (Jussaume et al., 2004). Monsanto's HR trait had been inserted into only one variety of wheat grown in a subset of U.S. and Canadian regions. It was opposed primarily by farmers who did not plant the potential HR variety and by some farmers who could have planted it but were afraid of losing access to European and Asian markets. Furthermore, during its deliberations, the present committee heard that North Dakota wheat farmers who were against the introduction of HR wheat because of concern about losing market access in Europe may now believe that they are disadvantaged by

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not having HR varieties and would like to see government and industry action that would lead to its development (Wilson, personal communication). Pest pressure is heterogeneous among growing regions, so support for or opposition to damage control through GE traits will vary according to farmers' abilities to benefit from them. Thus, the potential for collective action to restrain the power of the seed industry is a function of farmers' common interests, which are often variable.

Farmer cooperatives may also undertake efforts to bring about the introduction of seed traits that the private sector, for economic or other reasons, is not motivated to introduce. They may pool resources to undertake their own research or to defer the regulatory and development costs that private firms face when they introduce new seed technologies. Farmers have worked with universities to introduce new technologies (Bradford et al., 2006), and similar collaborations could be effective in the development of genetic-engineering technology. In California, grape growers have suffered considerable losses from Pierce's Disease, so they have contributed funds to the Public Intellectual Property Resource for Agriculture to support research for a genetic-engineering solution to the problem (PIPRA, 2006). More generally, pooled funds from farmers can lead to the introduction of desired traits for specialty crops when private seed companies lack the incentives to develop the traits alone (for more discussion of seed-access issues, see Chapter 3). As the price of wheat goes up, for instance, farmers in some regions may approach companies or universities to develop seed varieties to address specific constraints on productivity (Wilson, personal communication). They may also work with initiatives like the Specialty Crop Regulatory Assistance program, a fledgling collaboration of the federal government, scientists in public universities and the private sector, and farmers designed to assist technology developers in negotiating GE specialty crops through the requirements and expense of the regulatory process.

Despite the ability of farmers to organize collectively to counterbalance seed companies and processors, some farmers are concerned about the evolution of seed-technology innovation from a public good to a private good that is controlled by firms that have market power derived from patents on specific products. Innovation in most agricultural inputs is embodied in the technology, as in tractors and fertilizers. The technology is developed and sold by the private sector. But because it had historically been difficult to capture benefits from research efforts in seed technology before the advent of hybrid corn seed, the private sector underprovided seed-technology innovation, and the public sector took the lead in providing improved seed varieties in many crops (especially wheat, soybean, cotton, barley, and oat). Consequently, farmers who grew those crops—particularly wheat, barley, and oat—became accustomed to free or low-cost access to seed, and some farmers may consider open access to seeds a right.

In the case of GE seed, however, companies can make use of patent protection to enforce contracts that disallow reuse of the seed grown in farmers' fields. Farmers must instead purchase seed from firms to reward their research investment and effort. The patents enable the private sector to set prices for the protected technology and to restrict the flow of knowledge. The private sector had already begun to invest more in seed technology for major crops such as corn in the 1930s and soybean in the 1970s. Because of the difficulty and expense of removing lint from the seed, cotton farmers had traditionally purchased their seed from ginners and seed distributors. Consequently, the introduction of GE seeds by the private sector and the patented nature of the technology in the case of commercially available corn, soybean, and cotton may not have appeared to be strikingly different from the established relationship between seed companies and farmers of those commodities.

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However, the developmental trajectory of GE-seed technology is leading to concern that access to seeds without GE traits or to seeds that have only the specific GE traits of particular interest to farmers may become increasingly limited. Additional concerns are being raised about the lack of farmer input and knowledge regarding which seed traits might be developed. The push to develop seed varieties with a series of stacked traits, some of which may not be of use to some farmers with respect to short-term productivity (leaving aside the issue of improved resistance management discussed in Chapter 2), raises the issue of access to seeds that have equivalent yield potential but only the desired GE traits or no GE traits at all. Although the committee was not able to find published research that documents the degree of U.S. farmers' access to and the quality of non-GE seed, testimony provided to the committee suggested that access to non-GE or nonstacked seed could become limited for some farmers and that available non-GE or nonstacked seed may not have the same yield characteristics as GE cultivars (Hill, personal communication). Research is needed to investigate the extent to which U.S. farmers are having difficulty purchasing high-yielding, non-GE seed. Public-sector institutions could address this concern by improving the design of licensing contracts with seed companies so that property rights of privately developed traits or cultivars will revert to university research programs if private companies do not use the technologies.

Boejlje (1999) has suggested that U.S. agriculture is going through a structural change in which activities that will enhance product differentiation and added value to farming are being emphasized. As part of that evolution, many agricultural sectors (poultry, swine, and some fruits and vegetables) have come to be dominated by contracting arrangements between major agribusiness companies and farmers or by large vertically integrated agribusiness firms. Those large companies have the resources and scale to finance research in the development of GE traits. The emergence of alliances between biotechnology companies and large agribusiness firms, and even large farmers' cooperatives to produce proprietary GE varieties, appears possible, but future research is needed to determine whether such relationships can lead to the development of differentiated products (Boehlje, 1999)—including those with traits that enhance direct value to consumers, such as improving health or convenience, or that respond to the environmental and management needs of specific groups of farmers—and whether such relationships will limit farmers' access to the types of GE traits they value.

INTERACTIONS OF LEGAL AND SOCIAL ISSUES SURROUNDING GENETIC ENGINEERING

Legal issues constitute an important sociopolitical dimension that influences the adoption of genetic-engineering technology and its impacts on farmers and communities. The legal issues are complex, and a complete treatment of them is beyond the expertise of any of the authors of this report. We briefly touch here on the issues of seed saving, gene flow, and organic standards.

Seed Biotechnology

Courts in the United States and Canada have consistently upheld the rights of companies that sell patented seeds and genes through technology-use agreements to prohibit seed-saving practices that involve seed sold through those contracts (Kershen, 2004; Anonymous, 2008). Although that property right has been established, some continue to express concern about the

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ethical issues surrounding the patenting of life forms and over the effects of technology-use agreements on seed-saving practices. Research on whether those concerns are warranted and what the impacts are on farm sustainability are needed. Concerns are also being raised about the lack of farmer involvement in GE-trait development for traits that could address production problems identified by farmers and over the implications of current patenting procedures on power relationships between biotechnology firms and farmers (Phillipson, 2001). However, the social and economic effects of the exercise of such property rights, especially actual or potential litigation on both adopters and nonadopters of GE crops, have not been thoroughly investigated by social scientists. The lack of academic analyses of those issues may be due in part to the fact that companies, in any sector, that use the courts to enforce their property rights view legal actions and any out-of-court settlements as proprietary information. One interesting response by those who are concerned about the possible effects of the private control of genetic resources has been the open-source breeding movement.[5]

Gene Flow

A second set of legal issues related to genetic-engineering technology has to do with gene flow, particularly from fields of GE crops to those managed by people not using GE crops (for more on the potential for gene flow between GE and non-GE crops and on the challenges of coexistence of GE and non-GE crops, see Chapter 2). As in cases that involve restrictions on farmers against seed saving, these issues can be viewed as property-rights issues. Does gene flow impinge on the rights of producers and consumers who wish to grow and eat foods that do not include GE material (Conner, 2003)? That is of particular concern to some farmers who wish to produce organic or non-GE crops. Even though organic certification by the U.S. government is determined by the process used to grow the crop some farmers are concerned that their products may not be accepted by markets in other countries or by food distributors and consumers who establish their own standards, irrespective of process.

Several lawsuits have been filed by farmers against agricultural-biotechnology companies in part because of damage alleged to have occurred as a result of drift of genetic material to the fields of farmers who do not wish to grow crops with GE traits (Kershen, 2004). Consumer groups have also brought legal action against the federal government for approving the commercialization of GE crops that have the potential to cross with non-GE crops in the same vicinity. As was discussed in previous chapters, GE alfalfa was pulled from the market after a U.S. federal judge sided with arguments brought forward by numerous plaintiffs and found that USDA should have prepared an environmental impact statement before it deregulated the crop that facilitates commercialization (*Geertson Farms Inc.*, 2009). In another case filed by the Center for Food Safety and other plaintiffs, a federal judge decided in September 2009 that similar steps should have been taken before GE sugar beet was commercialized (Pollack, 2009).

Issues raised by the possibility of gene flow are not only legal in nature. As noted in Chapters 2 and 3, the adventitious presence of GE material in non-GE crops raises complex environmental and economic challenges. Similarly, social problems could arise as a consequence of gene flow,

[5]This movement, which has been inspired in part by open-source project movements in computer software and elsewhere, is in essence an attempt to develop publicly available genetic resources. As in the case of "shareware," researchers working on open-source biotechnology can access and improve on publicly available genetic resources and technologies but must agree to make the improved materials available for others to use (Delmer, 2005; Lerner and Tirole, 2005).

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particularly if GE and non-GE producers of the same commodity live in the same community. Gene-flow disputes could move beyond the merely legal and affect the overall functioning of communities where such disputes exist. This might include conflicts between farmers as well as stress related to the economic and social costs associated with lawsuits and the potential threat of lawsuits. Studies of the social effects of such disputes are needed to gauge the full impact on community well-being. The ability of GE production and non-GE production to coexist in society may depend on the health of communities. Proposals for establishing "landscape clubs" (Furtan et al., 2007) and voluntary "GMO-free zones"[6] (Jank et al., 2006) clearly depend on the existence of high levels of community cooperation, which could be undermined by disputes related to gene flow.

Organic Laws and Resistance to Genetic Engineering

One of the intriguing public debates that has emerged around genetic engineering in agriculture has been that regarding whether GE crops should be allowable in legal standards for organic agriculture. As discussed in Chapter 1, many organic growers have vehemently resisted the notion that GE crops should be allowable in organic agricultural production systems. However, scientific arguments can be made for the use of genetic-engineering technology for making organic agricultural production more sustainable. Ronald and Adamchak (2008) note that what is or is not an appropriate use of genetic-engineering technology for "organic" producers is problematic given that genetic-engineering techniques can be used to transfer genes within plant species as easily as between them. Genetic-engineering techniques also include the use of marker-assisted breeding wherein the genetic "fingerprint" of plants can be used to aid conventional plant breeding. These authors also note the potential for genetic-engineering technology to develop new varieties of crops that could be grown under conditions that reduce some of the adverse environmental impacts of growing food and that contribute to local food production. The rationale parallels the arguments used in discussing the potential of genetic-engineering technology for improving the productive capability of orphan crops in developing countries (Naylor et al., 2004).

The ideological divisions between those who favor and those who oppose the use of GE plants in organic production systems are complex, and in many cases concerns about safety and naturalness are connected to and mask socioeconomic concerns. An example of the complexity was the successful vote in Mendocino County, California, in 2004 to ban the local use of GE organisms in agriculture. The legal focus of the vote was on GE organisms, but it was clear, because of how genetic-engineering technology was linked to issues related to corporate versus local control of agriculture, that the technology was viewed by many of those supporting the measure as a social problem (Walsh-Dilley, 2009). Similarly, some genetic-engineering proponents argue for including GE products in organic standards and labels at the same time that they argue against the labeling of foods with GE content because they consider GE and non-GE foods to be substantially equivalent products (Klintman, 2002). That position can be understood, in part, as a desire to obtain the economic benefit of some labels while avoiding the cost of being associated with other labels. Those examples underscore the important socioeconomic and

[6]A group of growers concerned about the organic purity of an open-pollinated field crop may come together to form a "landscape club", a fee-based organization designed to increase their economic welfare by providing protection against contamination through gene flow from related GE crops. A zone free from genetically modified organism (GMO-free) would provide similar protection (Jank et al., 2006)

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sociopolitical dimensions in public debates about genetic-engineering technology. To reconcile those debates over the potential use of genetic engineering in sustainable and developing-country agriculture, it may be wise to heed the suggestion of Ronald and Adamchak (2008) and use various social, environmental, and economic criteria in making decisions on when to use and not to use genetic-engineering technology in agriculture.

CONCLUSIONS

Social dynamics and networks between farmers and within local communities play a substantial role in the decisions that farmers make with respect to the use of GE crops and likely are impacted by the use of and conflicts over those crops. Research on the adoption of other agricultural technologies has demonstrated substantial social impacts on a farm level and a community level. Those impacts include, but are not limited to: decreases to and change of composition in the agricultural labor force; better on-farm working conditions; changes in farm and agricultural-industry structure; increases in capital requirements for farmers; and a decline in the socioeconomic viability of some rural communities. Comparable research on the effects of GE crops is lacking, and although it is reasonable to hypothesize that the social impacts of the spread of GE crops have been low due to the assumed scale neutrality of this technology, it is equally reasonable to assume that the social impacts have been numerous and profound. Those questions cannot be answered without short- and long-term empirical research on the social processes surrounding, and the social impacts associated with, the adoption of genetic-engineering technologies at the farm level. Such research must take into account the various contextual factors that are influencing social changes on U.S. farms and rural communities.

Research has demonstrated that farmers' interest in genetic-engineering technology and patterns of adoption are influenced by farmers' social networks and by farmers' associations, private firms, and public actors, including universities. Research also has identified the continuing consolidation of the seed industry and its integration with the chemical industry. The market power of firms that supply seed has not adversely affected farmers' economic welfare so far, but research is needed on how market structure may affect ongoing access to non-GE or single-trait seeds and future seed prices. Furthermore, there has been comparatively little research on how changes in farmer social networks and seed-industry concentration might be affecting farmers' planting decisions and options, overall yield benefits, crop genetic diversity, and economic returns.

A final set of social issues has to do with complex legal issues, including the adoption of and the use of genetic-engineering technology. U.S. and Canadian courts have also upheld the legal rights of seed companies to prohibit seed-saving practices through the use of contracts. The issue of gene flow is complicated. One important question being raised is whether adventitious presence of genetic material from GE crops into non-GE crops impinges on the rights of producers, including organic producers, who do not wish to use specific GE traits. The legal debates may mask deeper social and ideological divisions over the use of GE plants and how to define and implement sustainable agricultural practices.

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5

Key Findings, Remaining Challenges, and Future Opportunities

The first generation of genetically engineered (GE) crops has mostly delivered effective pest control for a few major crops because farmers producing these crops spend a lot of time and money on the task, because the firms developing the new seed technologies saw considerable profit potential in doing so, and because adding the traits was relatively straightforward, requiring transformation of a genome at only a single location. The first generation of GE crops continues a reliance on pesticide technology—in-plant toxins or resistance to herbicides—to mitigate pest problems primarily in corn, cotton, and soybean. Thus, the application of genetic-engineering technology to crops has not developed novel means of pest control, such as developing plant mechanisms to resist pest damage, nor has it reached most minor crops.

The next set of challenges for the application of GE-crop technology is to expand to additional crops and to address additional desirable traits, such as drought tolerance, enhanced fertilizer utilization to reduce nutrient runoff, nutritional benefits, renewable energy production, and carbon sequestration. A number of those applications are under development by the private sector, some by the public sector. Clearly, the future agenda for genetic-engineering technology is extensive and of great importance for improvements in agricultural productivity and sustainability in a rapidly-changing world.

This chapter opens by summarizing the major findings of our assessment of the farm-level environmental, economic, and social impacts of GE crops. We then identify key remaining challenges that will frame future development and commercialization of genetic-engineering technology in crops. The discussion turns next to the future agenda of GE-crop applications, including general patterns of crop-trait development, implications for future weed-resistance management, and the potential role of GE crops for biofuels. The penultimate section highlights two subjects of research that the committee believes deserve more resources and effort: water quality and social impacts of GE crops. In closing, we discuss options for strengthening public and private research and development to exploit the potential of genetic-engineering technology to contribute more fully to environmental, economic, and social objectives.

KEY FINDINGS

The evidence shows that the planting of GE crops has largely resulted in less adverse or equivalent effects on the farm environment compared with the conventional non-GE systems that

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GE crops replaced. A key improvement has been the change to pesticide regimens that apply less pesticide or that use pesticides with lower toxicity to the environment but that have more consistent efficacy than conventional pesticide regimens used on non-GE versions of the crops. In the first phase of use, herbicide-resistant (HR) crops have been associated with an increased use of conservation tillage, in particular no-till methods, that can improve water quality and enhance some soil-quality characteristics. That farmers who practice conservation tillage are more likely to adopt GE crops suggests the two technologies are complementary.

At least one potential environmental risk associated with the first phase of GE crops has surfaced: some adopters of GE crops rely heavily on a single pesticide to control targeted pests, and this leads to a buildup of pest resistance regardless of whether GE crops or non-GE crops are involved. The governmental regulation of GE Bt crops through refuge requirements seems to have proved effective in delaying buildup of insect resistance with two reported exceptions, which have not had major consequences in the United States. Grower decisions to use repeated applications of particular herbicides to some HR crops have led, in some documented cases, to evolved herbicide-resistance problems and shifts in the weed community. In contrast with Bt-crop refuge requirements, no public or private mechanisms for delaying weed resistance have been extensively implemented. If the herbicide-resistance problem is not addressed soon, farmers may increasingly return to herbicides that were used before the adoption of HR crops. Tillage could increase as a pest-management tactic as well. Such actions could limit some of the environmental and personal safety gains associated with the use of HR crops. The newest HR varieties likely will have tolerance to more than one herbicide, and this would allow easier herbicide rotation or mixing, and, in theory, help to improve the durability of herbicide effectiveness. These new stacked varieties will be one more tool to help manage the evolution of weed as well as insect resistance.

The potential for gene flow via cross-pollination between current major GE crops and wild or weedy relatives is limited to cotton in small spatial scales in the United States because the other major GE crops have no native relatives. How this changes in the future will depend on what GE crops are commercialized, whether related species with which they are capable of interbreeding are present, and the consequences of such interbreeding for weed management. Gene flow (i.e., the adventitious presence) of legal GE traits in non-GE crops and derived products remains a serious concern for farmers whose market access depends on adhering to strict non-GE standards. It would appear that the resolution of the issue may require the establishment of enforceable thresholds for the presence of GE material in non-GE crops that do not impose excessive costs on growers and the marketing system.

The literature reviewed in this report indicates that a majority of U.S. farmers who grow soybean, corn, or cotton have generally found GE varieties with herbicide-resistance and insect-resistance traits advantageous because of their superior efficacy in pest control; their concomitant economic, environmental, and presumed personal health advantages; or their convenience. The extent of the benefits varies among locations, crops, and specific genetic-engineering technologies.

After some early evidence of yield disadvantages for some GE varieties in the United States, studies have now shown either a moderate boost in yields of some crops or a neutral yield effect. Some emerging evidence suggests that the attractiveness of the genetic-engineering technology for soybean, cotton, and corn has increased the global acreage planted to these crops over what would have been planted otherwise and thereby increased global commodity supplies (World Bank, 2007; Brookes and Barfoot, 2009). Consequently, the adoption of some of the GE crops

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around the world has put downward pressure on the prices received by U.S. farmers who are growing these crops, holding other factors constant. At the same time, livestock producers and consumers who purchase GE feed and food products may have benefited from the downward price pressure. However, the U.S. and world agricultural economies have been influenced by other factors that tend to increase commodity prices, making empirical verification of the effects difficult.

The economic effects of GE-crop adoption on nonadopters are mixed. To the extent that the use of genetic-engineering technology changes the types and amounts of inputs used, adopters of GE crops can influence the pesticide market. Changes in the price and availability of pesticides affect nonadopters as well. Farmers of non-GE crops in the vicinity of GE-crop farms may experience landscape-level effects from reduced pressure from pests targeted by GE traits. Marketing of non-GE crops may also be affected by GE crops, favorably or unfavorably. For example, products derived GE and non-GE crops can mix through gene flow or supply contamination. On the other hand, GE crops may create a market premium for non-GE products.

The historic social repercussions of introducing new technologies in agriculture, such as mechanization and the widespread planting of hybrid corn, have been studied extensively, and the results of the studies provide a basis for understanding the general effects of introducing GE varieties of crops. Despite the salience of those effects, however, there has been little investigation of farm-level and community-level social impacts of GE crops. The new seed technologies raise important potential social issues about farm structure, the input and seed choices available to farmers, and the genetic diversity of seeds. Among the known social facts associated with the dissemination of GE crops are the continued consolidation of the seed industry and its integration with the chemical industry. Another is the change in relationships between farmers and their seed suppliers. Testimony to the committee suggested that farmers of major crops have fewer opportunities to purchase non-GE seed of the best-yielding cultivars even when a GE trait is not perceived to be required in a particular cropping situation. As genetic-engineering technology matures and moves into its next phase, it is imperative that the full array of social issues involved be identified and investigated in depth.

REMAINING CHALLENGES FACING GENETICALLY ENGINEERED CROPS

Potential crop-biotechnology developments stir discussion around five issues. The treatment and resolution of those issues hold implications for long-term sustainability for farmers, including both adopters and nonadopters of GE crops.

First, the success of genetic-engineering technology in the United States has altered the seed industry by spurring consolidation of firms and integration with the chemical industry. Those developments continue to alter seed and pest-control options in the market, expanding pest-control options for some farmers and possibly limiting them for others, including those who do not grow GE crops. The resulting concentrated and legally enforceable private control of plant genetic material contrasts sharply with public plant-breeding programs that traditionally have fostered public access to discoveries, especially if GE varieties are developed for crops from which farmers have traditionally saved seed for the next year's crop (such as wheat, barley, and oat). Although corporate consolidation may offer greater economies of scale, it also is accompanied by the possibility of less competition and higher seed expenses, which may lower farmer returns, reduce pest-control options, and limit the benefits of commercialization of genetic-engineering technology to a few widely grown crops. There is not yet clear evidence of a

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these trends should be monitored, and their effects ameliorated to remedy social losses that result.

Second, how the intensive use of current and prospective GE organisms will directly affect the natural environment differently from other agricultural production systems is incompletely understood (Ervin et al., 2003). Relatively few studies have provided integrated assessments of the indirect effects of GE crops on pest damage to non-GE crops and on the full suite of ecosystem services on the landscape scale. For example, the concurrent effects on regional water quality of shifting tillage and pesticide regimens with the introduction of GE crops on regional water quality conditions remain poorly documented and understood. Knowledge of the spatial and temporal effects on ecological health—favorable or unfavorable—assumes greater importance as the evolution of herbicide resistance in weeds alters patterns of herbicide use to make up for the loss of glyphosate's efficacy on some species, and as novel GE plants, such as those for energy and nonfood uses, approach commercialization. Evaluation and monitoring of the ecological health of soils, water quality and quantity, and air quality will provide the information needed for developing the most productive yet sustainable agricultural systems for the future (Ervin et al., 2003).

Third, progress in developing GE varieties for most "minor" crops (e.g., fruits and vegetables) and for other "public goods" purposes not served well by private markets has been slow. Minor crops play important roles in the agricultural sectors of many states. Some minor crops, such as sunflowers and grain sorghum, have been considered to be poor candidates for the HR traits because of the existence of near-relative weeds (grain sorghum) or native ancestral populations (sunflowers). However, that risk does not explain the relative dearth of research and development (R&D) on GE varieties of minor crops as a whole, especially fruits and vegetables. The high fixed investment, patent protection involving GE traits, and the regulatory expense of commercializing GE seeds have lessened the ability of small companies and public-sector crop-breeding programs to develop commercially viable GE varieties of most minor crops. It seems clear that more effort should be devoted to the enhancement of minor crops with the best available genetic-engineering techniques even though the commercial rewards per crop may be small. Private and public R&D programs for GE crops have not yet led to the commercialization of many additional plant traits, such as improved tolerance to drought and increased fertilizer-use efficiency that decreases nutrient runoff, a contributor to nonpoint-source water pollution. This is not to suggest that GE seeds represent a "silver bullet" technology to solve all of these problems. Such GE trait developments may or may not turn out to be the most cost-effective approach to solving these issues, but exploration is necessary to evaluate their relative efficacy. Even though the basic technology is over 20 years old, agricultural biotechnology in some regards is still in its infancy. The rate of progress of genetic-engineering technology for some purposes suggests that more time and resources and new institutional relationships, such as public–private R&D collaborations, are desirable for the technology to reach its potential. Traits that have not yet received much attention, such as improved nutrient absorption and enhanced food value of crops, should be emphasized in the future so that we can gain the knowledge needed for weighing how the advances of genetic-engineering technology could present options for addressing all aspects of food supply, energy security, and environmental challenges.

Fourth, the presence of transgenic material in non-GE products should be addressed. The current definition of organic food in the United States excludes the use of GE materials in production and handling processes, so organic farmers must take steps to ensure that their production methods do not expose their crops to GE traits. To avail themselves of market

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premiums for certified organic crops, they must incur costs for keeping their products separate from GE crops. Food producers who market products as non-GE face similar challenges to prevent co-mingling of GE and non-GE crops during storage and distribution. In those ways, the introduction of GE crops influences the decisions and operations of farmers and food producers who do not use the technology.

Fifth, U.S. farmers who grow GE crops may face market restrictions from some countries or retail firms on the importation or sale of the crops or products made from the crops. Under some international agreements, some countries impose these restrictions because of perceived food safety or environmental risks or for other reasons. Assuming that those actions satisfy international treaty rules, such market-access restrictions to some extent slow the development of a global market for GE crops. One effect of the trade restrictions has been to limit the market demand for GE crops.

The potential of GE crop varieties to address the world's emerging food-supply, energy, and environmental problems hinges on how those challenges are resolved. Success in resolving them may allow genetic-engineering technology to become even more transformational in fostering sustainable agricultural systems for farmers. This important agenda frames the discussion of future GE-crop applications.

FUTURE APPLICATIONS OF GENETICALLY ENGINEERED CROPS

In addition to expanding existing GE traits into other crops, the reach of genetic-engineering technology could be extended through the development and commercialization of new traits. Traits beyond those designed to control pests could have substantial benefits in fields other than agriculture, such as food and energy security. This section summarizes the present pattern of R&D of novel GE traits in the private and public sectors and highlights areas in which new traits could be especially useful to improving agricultural sustainability.

Patterns of Genetically Engineered Products in Development

The GE crops now being planted by U.S. farmers were developed over long gestation periods. Given that fact, the current portfolio of GE crops does not wholly capture the range of new crops being readied for commercialization that could cover the U.S. farm and global landscape in the future. For instance, companies are developing crops with more intricate pest control mechanisms (see Box 5-1), but they are also engineering traits that improve crop tolerance to stress or that provide benefits directly to consumers. Recent research also indicates that novel forms of pest control may be part of the next generation of GE crops. As an example, Baum et al. (2007) report positive laboratory findings that ribonucleic-acid (RNA) interference technology, a plant-based method for pest management, results in larval stunting and mortality in several coleopteran species controlled by Bt crops. Predicting future crop biotechnologies is somewhat difficult because companies, for reasons of competitiveness and patent protection, may not fully share the specifics of planned releases. However, three recent global surveys of product-quality innovations in the development phase of genetic-engineering technology help in discerning general trends in GE-crop development and, in particular, why quality-improving innovations from genetic-engineering technology have not yet been more numerous (Graff et al., 2009).

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BOX 5-1
New Traits Reduce Refuge Requirement and Introduce Second Mode of Herbicide Resistance

On July 20, 2009, the Environmental Protection Agency (EPA) announced final approval for commercialization of SmartStax™ corn hybrids. These hybrids produce multiple proteins for the control of lepidopteran pests and for the control of corn rootworm (two of these proteins must be used together to induce significant rootworm mortality). The hybrids also have transgenes conferring resistance to glyphosate and glufosinate. Because of the multiple toxins affecting single pests, this group of hybrids was approved by EPA with a refuge requirement of 5 percent in the Corn Belt and 20 percent in the Cotton Belt (US-EPA, 2009). Those refuge requirements are reduced from the original requirements of 20 percent in the Corn Belt and 50 percent in the Cotton Belt for previous transgenic Bt corn hybrids. Resistance to the different broad-spectrum herbicides may help in delaying the evolution of resistance in weeds in areas where glyphosate-resistant populations have not been identified. However, growers must assume appropriate stewardship for these herbicides in order to manage the future evolution of herbicide-resistant weed populations.

The combined findings of the surveys show that less than 5 percent of the innovations reach the regulatory and commercialization phases. As might be expected, R&D activity has been uneven among different trait categories because of variation in the difficulty of achieving selected transformations and in the economic value of the traits. For example, traits governing content and composition of macronutrients—proteins, oils, and carbohydrates—and traits that control fruit ripening have more readily reached later stages of R&D, and few products with enhanced micronutrients, functional food components, or novel esthetics have approached commercialization (Graff et al., 2009). The analysts concluded that product-quality innovation appears more responsive to demand in intermediate markets for processing and feed attributes than to demand in retail markets for improved or novel products. They also noted that many of the observed traits offer potential efficiency gains in agriculture and improvements in natural-resource systems and a potential to reduce environmental impacts both because they will decrease input requirements and because they will reduce adverse externalities of crop production, processing, or consumption. For example, new traits may increase the efficiency of livestock-feed digestibility and by so doing increase the value of the feed to farmers. Traits that improve nitrogen-use efficiency that are on the horizon will bring value to farmers and could contribute to reducing agriculture's effects on water quality. The potential for environmental improvement from such traits depends on the degree to which they improve input-use efficiency and the extent to which farmers expand production because of lower unit costs.

The rate of product-quality innovations in genetic-engineering technology identified in the surveys decreased considerably after 1998. The authors noted that the cause of the decline remains conjectural. It coincided with the decrease in the number of transgenic field trials conducted in the United States and Europe, with the exit from the market of a number of small biotechnology companies that were not deeply involved in the first generation of GE pest-control crops, and with changes in the regulatory environment in Europe that restricted the introduction of GE varieties there.

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Data on field tests of crop-biotechnology innovations corroborate the slowdown. A critical part of new variety development is field testing to ensure that the desired traits will perform under commercial production conditions and that no important environmental risks are associated with release of a GE organism. The release of new GE varieties or organisms into the environment is regulated, in part, through field-release permits monitored by the U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) (Fernandez-Cornejo and Caswell, 2006).[1] The overall number of field releases of plant varieties for testing purposes is a useful indicator of R&D efforts in GE crops. By the end of 2008, about 15,000 applications had been received by APHIS since 1987, and nearly 14,000 (93 percent) had been approved (ISB and USDA-APHIS, 2009). Annual applications peaked in 1998 with 1,206, and annual approvals peaked in 2002 with 1,141 (Figure 5-1). Most applications approved for field testing in 1987–2008 involved major crops, particularly corn with 6,648 applications approved, followed by soybeans (1,554), cotton (912), potato (817), tomato (637), wheat (413), alfalfa (385), and tobacco (363). Applications approved during this time included GE varieties with herbicide resistance (25.1 percent), insect resistance (20.1 percent), improved product quality (flavor, appearance, or nutrition) (18.2 percent), and agronomic properties, such as drought resistance (13.4 percent) (Figure 5-2).

After sufficient field testing, an applicant may petition APHIS for a determination of "nonregulated" status to facilitate commercialization of a product. If, after extensive review, APHIS determines that unconfined release does not pose a substantial risk to agriculture or the environment, the organism is "deregulated" and can be moved and planted without APHIS authorization (Fernandez-Cornejo and Caswell, 2006). Petitions for deregulated varieties peaked in 1995–1997 with 14-15 petitions per year and have been below 10 petitions every year thereafter (ISB and USDA-APHIS, 2009). As of June 5, 2009, APHIS had received 119 petitions for deregulation and had approved 76. The deregulated varieties had HR traits (38 percent), IR traits (28 percent), product-quality traits (15 percent), virus-resistance traits (11 percent), and agronomic traits (6 percent) (ISB and USDA-APHIS, 2009).

[1] If a plant is engineered to produce a substance that "prevents, destroys, repels, or mitigates a pest", it is considered to be a pesticide and is subject to regulation by the Environmental Protection Agency (Fernandez-Cornejo and Caswell, 2006). Thus, all Bt crops are included.

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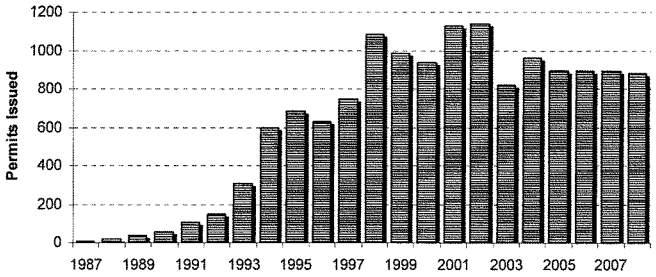


FIGURE 5-1 Number of permits for release of genetically engineered varieties approved by APHIS.
SOURCE: ISB and USDA-APHIS, 2009.

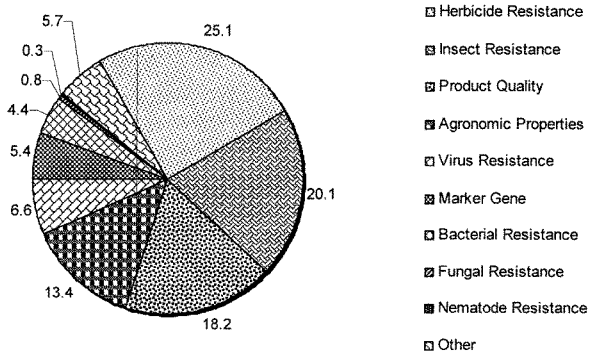


FIGURE 5-2 Approved field releases of plant varieties for testing purposes by trait (percent).
SOURCE: ISB and USDA-APHIS, 2009.

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Another study of the APHIS GE-crop release data investigated the private or commercial and public-goods aspects of traits being tested (Welsh and Glenna, 2006). The authors analyzed releases in 1993–2002 to answer two research questions (p. 936):

- "To what extent have universities mimicked the for-profit sector in agricultural biotechnology by focusing their transgenic research on a relatively few proven genotypes (traits)?"
- "To what extent have universities mimicked the for-profit sector in agricultural biotechnology by focusing their transgenic research on the relatively few major (commercially dominant) agronomic crops?" (Welsh and Glenna, 2006, p. 936)

They categorized the crop releases into major traits—herbicide resistance, insect resistance, and product quality—and "other" GE traits. Product quality includes the alteration of a particular crop's characteristics to make it more valuable to food, feed, or energy manufacturing firms, such as a higher lysine concentration in corn that would be useful to livestock producers. Other GE traits were nematode resistance, fungus resistance, bacterium resistance, virus resistance, and agronomic properties (such as yield). They also categorized the releases by whether they were major crops (soybean, corn, wheat, alfalfa, and cotton) or minor crops (such as other field crops, vegetables, and fruits planted on smaller acreages).

The results indicated that the research profiles of universities in 1993–2002 were less dominated by the major traits than were the profiles of for-profit firms. A similar pattern emerged for major crops: about 71 percent of notices filed with APHIS by for-profit firms entailed research on major crops compared with 32.6 percent filed by universities. Moreover, work on minor crops differed among universities depending on their region (for example, apples in the Northeast and citrus in the Southeast). The authors examined whether the relationships changed during three periods: 1993–1995, 1996–1998, and 1999–2002. The research profiles of the for-profit firms remained fairly uniform, but universities looked more like for-profit firms in the later periods. That trend was especially pronounced for major traits: almost 73 percent of notices filed by universities entailed at least one major trait in 1999–2002 compared with around 35 percent in earlier periods. The proportion of research on major crops by universities also increased.

To probe those relationships in more depth, Welsh and Glenna constructed a commercial index for each release. The index was computed by assigning scores of 1 for research on a major crop and 1 for research on a major trait. Research on a minor crop was scored as -1 and research on a minor trait was scored as -1. Possible index values were therefore 2, 1, 0, -1, and -2. A higher index value indicated greater research emphasis on more commercially relevant crops and traits, and a lower value indicated more emphasis on crops and traits with smaller markets. Plotting the value of the index for universities and private-sector firms over time revealed that universities and private-sector firms showed increasingly similar research trajectories, which emphasized major crops and major traits in genetic-engineering technology. The time-series relationship was also found to be statistically significant (Welsh and Glenna, 2006).

Results of those three studies of GE-trait developments indicated that some GE products in various phases of development serve purposes other than pest-control traits dominant today, but they have not been commercialized. The reasons for this vary with the crop and the trait, but include a small anticipated market, lack of access to technology, uncertainty about consumer acceptance, potential spillover to weedy relatives or gene transfer to non-GE cultivars, and high regulatory costs. During the process of innovation, commercialization, and adoption, all

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organizations weigh the costs and benefits of their decisions (Bradford et al., 2006). It is not surprising that the GE crops that were commercialized first provided substantial net benefits to the innovators, the seed companies, and adopting farmers.

Implications of Genetically Engineered Crops for Weed Management

An unmet challenge for GE crops documented in Chapter 2 revolves around sustaining the efficacy of particular herbicides. Maintaining their efficacy holds important implications for future farm economics and environmental sustainability. A key concept in understanding herbicide-resistance effects in weeds is the open, unregulated access of all farmers to the common pool of pest susceptibility. The presence of this condition leads to individual decisions that may impose user costs on the whole population of farmers, to suboptimal overall management, and to increasing total social costs (Hardin, 1968).

The data show that GE-crop cultivars resistant to glyphosate dominate in the corn, soybean, and cotton production regions across the United States. Results of a six-state survey to assess crop rotations by growers of GE crops showed that rotation of a GE crop with a non-GE crop was most commonly followed by rotation of a GE crop with a GE crop (Shaw et al., 2009). Rotation of a GE with a non-GE crop was more common in the Midwest than in the South. With the high acreage of glyphosate-resistant crops being planted, substantial changes in herbicide use occurred; notably, fewer herbicides were used (Young, 2006); the most common current herbicide tactic reported is one to three applications of glyphosate (Givens et al., 2009). A related change in production practice attributable to the adoption of HR crops that has implications for weed management was the increased adoption of conservation tillage (Givens et al., 2009). The overall grower assessment of the effect of HR crops on weed population densities was that there were fewer weeds because of the use of glyphosate on HR crops (Kruger et al., 2009). Few growers felt that weed populations would shift to species that had evolved resistance to glyphosate, understood the importance of alternative tactics to control weeds, or perceived the role of selection pressure caused by the use of glyphosate on HR crops (Johnson et al., 2009). Given that changes in weed communities in response to production practices have been a consistent problem in agriculture, future weed challenges are likely to increase quickly (Baker, 1991; Owen, 2001; Heard et al., 2003b; Heard et al., 2003a). To summarize, growers valued the immediate benefits of weed control without appreciating the long-term risks attributable to the tactics they used. That behavioral response might be expected given many farmers' desire to meet short-run financial needs and the fact that other growers may not take similar control actions.

Recent survey data show that growers emphasize the convenience and simplicity of the glyphosate-based cropping systems while discounting the importance of diversification of weed-management practices (Owen, 2008b). That prevailing attitude has several likely results: given growers' apparent unfamiliarity with or lack of concern about the implications of selection pressure for weed communities, weed shifts are inevitable; and growers' short-term interest in killing weeds rather than managing them will result in the loss of crop yield and farm profits in the long run unless innovation in weed-control technology occurs. The efficacy of glyphosate on a broad spectrum of weeds, its ability to kill larger weeds, and the fact that glyphosate can be applied to HR crops almost regardless of crop stage of growth all reinforce growers' perception of the simplicity and convenience of glyphosate-based programs.

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Weed management implies that there is a critical period of weed control (CPWC) when weed interference must be eliminated to protect crop-yield potential (Nieto et al., 1968; Kasasian and Seeyave, 1969; Swanton and Weise, 1991; Knežević et al., 2002; Knežević et al., 2003). The CPWC is the same whether the crop is GE or non-GE. There is considerable information about the proper timing of glyphosate applications that will provide protection of yield potential and the related economic loss of crop yield in response to untimely glyphosate application (Gower et al., 2003; Dalley et al., 2004; Cox et al., 2005; Cox et al., 2006; Stahl, 2007). Many growers may recognize the relationship between early weed interference with HR crops and the resulting economic loss to profitability or may face high individual cost or risk in changing their behavior. The perception of success with glyphosate results in the repeated use of this herbicide without consideration of alternative strategies. Recurrent application of any herbicide will cause shifts in the weed community that support the evolving dominance of weeds that are not susceptible. Growers must use diversified weed-management practices, recognize the importance of understanding the biology of the cropping system, and give appropriate consideration to more sustainable weed-management programs (Knežević et al., 2003; Owen and Zelaya, 2005; Owen, 2008a). Furthermore, unless growers collectively adopt more diverse weed-management practices, individual farmer's actions will fail to delay herbicide resistance to glyphosate because the resistant genes in weeds easily cross farm boundaries. Some form of private or public collective action may avert this classic management of the commons problem in which individual actions to apply glyphosate have adverse spillover effects on the entire community of farmers (Hardin, 1968). Further research that results in new HR traits and other efficient means of weed control likely will lessen this problem.

Potential for Biofuels

Amid diminishing reserves of fossil fuels, heightened concern about climate change, and growing demand for domestic energy production, biofuels have emerged as an important supplementary fuel that may have considerable potential in supplying future energy needs. First-generation biofuels are serving as fuel extenders, displacing only a small percentage of gasoline consumption in the United States (Energy Information Administration, 2007). Nevertheless, because some existing biofuel crops can be produced in a manner that reduces greenhouse-gas emissions relative to fossil fuels and because they reduce dependence on volatile oil import markets, governments around the world have supported production of biofuel crops with subsidies and mandates (Koplow, 2007). However, although, as noted, some biofuel technologies can reduce greenhouse-gas emissions (Farrell et al., 2006), that might not always be the case, depending on production practices (Fargione et al., 2008; Searchinger et al., 2008). Furthermore, when they increase the demand for food crops, biofuel production can contribute to higher prices and shortages of food like those witnessed in 2008 (Tyner and Taheripour, 2008; Sexton et al., 2009).

In the United States, ethanol is produced principally from corn, approximately 80 percent of which is grown with GE varieties. Similarly, biodiesel in the United States is produced almost entirely from soybean; about 92 percent U.S. acres in soybean produce GE varieties. If those GE crops have increased yields, they may reduce biofuel costs.

If developed appropriately, new GE-crop technologies could play an important role in ameliorating further the adverse economic and environmental impacts of biofuels (Sexton et al., 2009). Indeed, some governments, like that of the United States, have tailored their biofuels

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policy to include, among other instruments, some support for next-generation technologies to overcome existing limitations (e.g., Rajagopal et al., 2007; Rajagopal and D.Zilberman, 2008). For example, genetic-engineering technology may help to improve the agronomic characteristics of plants used for cellulosic ethanol, which are not yet widely commercialized. Whereas ethanol is produced today only from the starch in plants, developments in microbiology allow the cellulosic material to be converted to biofuel. Genetic-engineering technology holds the potential to generate higher yields of these crops and to improve the amount of liquid fuel obtainable per plant by altering plants' genetic code in beneficial ways. It may provide these benefits without environmental damage. Because many of the plants that may provide fuel in the future have not been commercially farmed, it may be possible to improve plant genetics to maximize their energy-yield potential, minimize the costs of converting cellulosic plant material to liquid fuel, and devise best-management practices or mitigation for the environment.

RESEARCH PRIORITIES RELATED TO GENETICALLY ENGINEERED CROPS

Water-Quality Monitoring and Evaluation

Nonpoint pollution is the leading cause of water-quality impairments across the United States, extending into ocean estuaries, bays, and gulfs (US-EPA, 2007). Agriculture remains the largest source of these nonpoint pollution flows by volume, and much of the pollution stems from cropland operations. The predominant contaminants include sediment from land erosion and nutrient and pesticide residues not used or retained for growing crops. For example, a recent analysis estimated that agriculture contributes 70 percent of the nitrogen and phosphorus that enters the Gulf of Mexico and that corn production accounts for the majority of the nitrogen and corn and soybean production account for one-fourth of the phosphorus (Alexander et al., 2008). Particularly in view of the huge dead zone that has formed in the Gulf of Mexico, lessening such pollution has high national priority.

As explained in Chapter 2, evidence has begun to emerge that GE crops are often associated with changes in cropping practices that should lead to an improvement in the nation's water quality. The changes include shifts to conservation tillage or no-till techniques that leave more residues on the cropland surface and thereby reduce water runoff that contains sediment, nutrient, and pesticide contaminants. They also include the use of pesticides, such as glyphosate, that are less toxic and more quickly degrading than conventional crop herbicides and insecticides. The latter effects could also reduce contamination of groundwater and wells on farms from spills and mixing operations.

Because monitoring and research resources have been inadequate, those potential water-quality impacts of GE crops have not been documented. The committee received testimony from the U.S. Geological Survey that explained the lack of comprehensive data and analysis that could identify and estimate the magnitude of the potential improvements in water quality (Gilliom and Meyer, personal communication). Those effects are among the largest environmental effects of agriculture, and we recommend that more resources be devoted to the important tasks of spatial and temporal monitoring of how agricultural practices influence water quality. Monitoring changes associated with the adoption of GE cultivars is important given that the rapid, widespread adoption of those cultivars may have large impacts on water quality by changing agricultural practices. The resulting information could influence the design of future

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environmental policies and agriculture programs. Such critical intelligence would help to improve the efficacy and cost-effectiveness of achieving regional and national water-quality standards, and thereby improve farm sustainability.

Social Issues in the Use of Genetically Engineered Crops

Accumulated research in the social sciences has verified that the processes of technological development and diffusion do not take place in a social vacuum. Choices made by those who create new technologies and decisions made by others regarding whether to use the technologies are influenced by political, economic, and sociocultural factors. The social impacts of the use of the technologies are influenced by the same factors. A particular technology can have dissimilar social impacts depending on the context within which it is adopted. It is reasonable to hypothesize, on the basis of the existing body of knowledge, that the adoption of particular genetic-engineering technologies has a variety of social, economic, and political impacts, and that these impacts would not be the same at all times and in all regions and cultures.

As noted in Chapter 4, the amount of research on the social processes and effects associated with the development and use of GE crops has been inadequate and has not matched what took place previously in the cases of agricultural mechanization or even the use of bovine somatotropin in dairy production. Thus, there is little empirical evidence to which the present committee can point to that delineates the full array of social impacts of the adoption of GE-crop technology. That includes a lack of research on the social impact on farmers of companies legally enforcing their intellectual property rights in GE seeds. Research that has been conducted on the role of industry–farmer social networks in influencing the development of new seed technologies, legal issues related to GE-crop technology, resistance to the use of the technology in organic production systems, and the development of the open-source breeding movement does suggest, however, that genetic-engineering technology is socially contested by some groups. Those findings and trends reinforce the need for research on the social processes associated with genetic-engineering technology, including its social impacts, to inform the decision-making processes of technology developers, farmers, and policymakers. The committee recommends the development of this research agenda, which should lead to findings important for addressing the sociocultural issues that will arise in connection with broader adoption of GE crops in the future.

ADVANCING POTENTIAL BENEFITS OF GENETICALLY ENGINEERING CROPS BY STRENGTHENING COOPERATION BETWEEN PUBLIC AND PRIVATE RESEARCH AND DEVELOPMENT

The rapid adoption by U.S. farmers of the first generation of GE soybean, cotton, and corn varieties illustrates the speed and scope with which agricultural systems can be improved if appropriate products and systems are available. This report documents how GE varieties contribute to the sustainability of agriculture related to the production of those major crops. Expanding the effects to additional crops and further improving the technology will require an expansive program of R&D. Private companies are already working to develop additional traits that will improve the productivity and sustainability of agriculture in the United States and worldwide. However, both the private and public sectors must play vigorous, if often times

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different, roles if the full potential of genetic-engineering technology to foster a more sustainable agriculture is to be realized. In developing analogous traits for other crops, such as GE varieties of "minor" crops and additional GE traits to meet broader public environmental and social objectives (e.g., improved water quality and carbon sequestration), the active involvement of universities and nongovernment institutions will be crucial given the flexibility of such institutions in selecting research objectives when funding is available. Developing the most appropriate agenda for such research will require extensive stakeholder involvement, including input from adopters and nonadopters of GE crops, environmental and social interest groups, and industry representatives.

Public investment and innovation in genetic-engineering technology includes several phases, such as discovery, scaling-up of innovations, regulatory research, commercialization, production, and marketing. Life-science innovations increasingly take place within the educational–industrial complex, where research universities and public research institutions are engaged mainly in the early stages of innovation, and startup and major corporations are engaged more in product development (Graff et al., 2009). Much of the academic research addresses basic problems with uncertain outcomes that may result in new commercial innovations or in knowledge that has either pure public-good properties in the economic sense, such as basic-research discoveries that are nonrival and nonexclusive (Just et al., 2008), or properties that are not easy to appropriate, so revenues cannot be collected. Thus, such academic research will receive underinvestment by the private sector and warrants public-sector support (Dasgupta and David, 1994; Dasgupta, 1999).

Not all discoveries from academic research in genetic-engineering technology result in nonrival and nonexcludable products. For example, some scientists patent their innovations; these are then excludable products that can be licensed to other scientists, nonprofit organizations, or industry. A national survey in 2004 revealed that about 25 percent of responding scientists had filed for a patent since 2000. About 15 percent of the scientists had been issued a patent, and just under 8 percent had licensed their invention for use by private or public parties (Buccola et al., 2009). The responding scientists expressed slight support for patenting compared to the belief that publicly supported scientists should focus on knowledge with nonexcludable benefits (a mean of 2 versus a mean of 5 on a 6-point scale) (Buccola et al., 2009). Some scientists may be inclined to patent their discoveries in case they contribute to future, commercially developed technology.

In those cases where university discoveries and innovations are basic proofs of concepts, the private sector often undertakes the development effort, upscaling manufacturing capacity and commercializing the technology. Companies that invest in development of university innovations frequently buy rights to university patents to secure intellectual property protection and monopoly power once the products are developed. Without that protection, the firms may be unwilling to invest the capital necessary to move the technology to the commercialization stage.

There is likely to be underinvestment in commercialization of biotechnology innovation by the private sector because companies with implicit monopoly rights associated with patents aim to maximize their own profit without taking full account of consumers' welfare gains that result from the lower prices associated with an innovation. Firms cannot capture the potential benefits external to farmers and consumers, such as reduction in downstream pollution. The underinvestment in research makes a case for public-sector development of GE varieties as long as social benefits exceed social costs or social-equity objectives defined by elected representatives are achieved (de Gorter and Zilberman, 1990; Just et al., 2008). The situation suggests that public-sector research should emphasize the development of genetic-engineering

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technologies in specialty crops and innovation of other kinds, such as traits that may lead to a reduction in greenhouse-gas emissions from crop or livestock production or novel varieties that conserve water resources. The ability of the public and private sectors to develop new gene technologies depends on the costs of innovation, which may include access to intellectual-property rights and regulatory requirements. A tailored and targeted regulatory approach to GE-crop trait development and commercialization that meets human and environmental safety standards while minimizing unnecessary expenses could enhance progress on this front (Ervin and Welsh, 2006).

In reinforcement of those conceptual points, recent studies of genetic-engineering R&D have concluded that publicly funded research programs can complement private-sector R&D efforts in developing the full potential of agricultural biotechnology (Graff and Zilberman, 2001; Glenna et al., 2007; Buccola et al., 2009). There are several reasons for that conclusion. First, federal and state support encourages more basic research, whereas industry and foundations support more applied research in U.S. universities (Buccola et al., 2009). Downstream (i.e., more applied) research tends to be legally and economically more excludable than upstream (i.e., more basic) research. Publicly funded research offers the highest potential for achieving public goods, such as the basic science of genetic mechanisms, broadly accessible platform technologies, and nonmarket environmental services (Buccola et al., 2009). Second, industry collaborations with academic scientists have affirmed the necessity of a strong independent university research sector in helping to provide credible evaluations of new technology (Glenna et al., 2007). Third, both publicly and privately supported research assist in the transfer of basic discoveries in genetic-engineering technology, such as plant-genome characterizations, into useful crop-plant applications (Graff and Zilberman, 2001). For example, publicly supported basic research on *Arabidopsis thaliana* has provided an enormous store of information on basic plant biology, which in turn has enhanced our ability to produce commercially important advances in crops of all kinds. New institutional mechanisms are needed to provide an uninterrupted "pipeline" from basic research to field application (Graff et al., 2003). Fourth, commercialization of orphan and minor crops requires a special role for public R&D because the improvement of such crops often will not lead to sufficient profit to attract private-sector investment, even though the crops are important to many farmers and consumers. Fifth, public funding of academic research and government research fosters investigation that is too risky, or not sufficiently profitable, to be attractive to the private sector.

The evidence assembled in this report makes clear that the first generation of GE soybean, cotton, and corn varieties has generally been economically and environmentally advantageous for U.S. farmers who have adopted the technologies. The next generation of genetic-engineering technologies being reported by industry suggests that it is intent on enhancing those benefits and going beyond to new traits, such as drought and heat tolerance and enhanced fertilizer utilization that may indirectly reduce nutrient runoff, and new applicability to minor crops, renewable energy, climate change, and nutritional qualities. The public sector must complement industry by developing genetic-engineering technologies for crops that have insufficient markets to justify R&D and regulatory expense and to develop socially valuable public-goods applications. We envision the research and technology agenda to include individual private and public activities as well as private–public collaborations and to encompass work on the three essential components of sustainable development: environmental, social, and economic. Furthermore, we recommend that this agenda be undertaken in a program of research, technology development, and education that maximizes the potential synergies between the two sectors and their strengths and that limits

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redundancies and tradeoffs. Such an integrated approach would have universities, government, and nonprofit organizations leading in the development of traits that deliver public goods, including basic discoveries and such environmental issues as improved regional water quality. The private sector would continue to lead in the commercialization of GE crops for which there are adequate market incentives.

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Appendix A

Herbicide Selection

Herbicide[a]	Classification[b]	Mode of Action[c]	Relative Toxicity
Haloxyfop (Aryloxyphenoxypropionates) Clethodim (Cyclohexanediones) Pinoxaden (Phenylpyrazolines)	ACCase inhibitors ($A^{(1)}$)	Inhibitor of acetyl coenzyme-A carboxylase, a pivotal enzyme in plant fatty acid biosynthesis.	Varies based on specific chemical compound; likely to be carcinogenic to humans according to EPA *Proposed EPA Weight-of-the-Evidence Categories* (US-EPA, 2009a).
Alachlor (chloroacetanilides) Diphenamid (acetamides) Flufenacet (oxyacetamides) Fentrazamide (tetrazolinones)	Mitosis inhibitors ($K_3^{(15)}$)	Inhibition of cell division (long-chain fatty acid inhibitor).	Slightly toxic; oral RfD of 1×10^{-2} mg/kg-day. Critical effects: hemosiderosis, hemolytic anemia (US-EPA, 2009b).
Bensulfuron-methyl (Sulfonylureas) Imazethapyr (Imidazolinones) Cloransulam-methyl (Triazolopyrimidines)	ALS inhibitors ($B^{(2)}$)	Inhibition of the acetolactate synthase (ALS) enzyme resulting in cessation of the biosynthesis of essential branched chain amino acids (leucine, valine and isoleucine).	Varied; generally low acute and chronic toxicity to humans and not likely to be carcinogenic.
Atrazine (Symmetrical triazines)	Photosynthesis II inhibitors ($C_1^{(5)}$)	Inhibit photosynthesis by binding with a specific protein in the photosystem II complex.	Slightly to moderately toxic; oral RfD of 3.5×10^{-2} mg/kg-day. Critical effects: decreased body weight gain (other effect: cardiac toxicity and moderate-to-severe dilation of the right atrium (EXTOXNET, 2009a; US-EPA, 2009c).
Dicamba (benzoic acids)	Synthetic auxins ($O^{(4)}$)	The specific mode of action is not well defined, however these herbicide mimic endogenous auxin (IAA) and appear to negatively affect cell wall plasticity and nucleic acid metabolism.	Relatively non-toxic. Acute oral LD_{50} in rats ia 1707 mg/kg, dermal LC_{50} in rabbits is >2000 mg/kg. However, eye irritation in rabbit is extreme.

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Herbicide[a]	Classification[b]	Mode of Action[c]	Relative Toxicity
Glufosinate (organophosphorus)	glutamine synthetase inhibitor ($H^{(10)}$)	Inhibits the activity of glutamine synthetase which causes ammonia build-up in the cell. The ammonia destroys cell membranes.	Practically nontoxic by ingestion; some increase in absolute and relative kidney weights in males. No observed carcinogenesis. Oral RfD of 4×10^{-4} mg/kg-day (NPIC, 2009; US-EPA, 2009d).
Glyphosate (organophosphorus)	Enolpyruvyl shikimate-3-phosphate (EPSP) synthase inhibitor ($G^{(9)}$)	Inhibits the EPSP synthase which leads to depletion of essential aromatic amino acids (tryptophan, tyrosine, and phenylalanine).	Generally nontoxic. Increased incidence of renal tubular dilation in third generation weanlings. Oral RfD of 1×10^{-3} mg/kg-day (US-EPA, 2009e).
Amides, pyridiazinones, pyridines, isoxazoles, pyrazoles, triazoles, triketones and others	Carotenoid biosynthesis inhibitors	Inhibit the catabolic degradation of tyrosine to plastoquinones (important for photosynthesis and carotenoid biosynthesis) and tocopherol (vitamin E, which protects biological membranes against oxidative stress and the photosynthetic apparatus against photo-inactivation)	Varied; developmental toxicity, probable human carcinogen, phytotoxic (US-EPA, 2004, 2006, 2009f, g).
Fluridone (unclassified)	($F_1^{(12)}$)	Inhibition of phytoene desaturase, an enzyme essential for carotenoid biosynthesis	
Mesotrione (triketones)	($F_2^{(28)}$)	Inhibition of hydroxyphenylpyruvate dioxygenase (HPPD), an enzyme involved in the synthesis of plastoquinone (PQ) and tocopherol (vitamin E).	
Amitrole (triazoles)	($F_3^{(11)}$)	Target site is generally considered unknown with the exception of amitrole which inhibits lypopene cyclase and clomazone that is reported to inhibit an early step in the non-mevalonic acid isoprenoid pathway ultimately leading to carotenoid synthesis.	
Metribuzin (triazinones, asymmetrical triazines)	Photosynthesis II inhibitors ($C_1^{(5)}$)	Inhibit photosynthesis by binding with a specific protein in the photosystem II complex.	A slightly toxic compound in EPA toxicity class III. Liver and kidney effects, decreased body weight, mortality; no indications of carcinogenic effects. RfD of 2.5×10^{-2} mg/kg-day (EXTOXNET (Extension Toxicology Network), 2009b; US-EPA, 2009h).

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Herbicide[a]	Classification[b]	Mode of Action[c]	Relative Toxicity
dicarboximide herbicides, triazolone herbicides, diphenylethers, N-phenylphthalimides, oxadiazoles, thiadiazoles, triazolinones, and others	Protoporphyrinogen Oxidase (PPO) inhibitors ($E^{(14)}$)	Inhibits the protoporphyrinogen oxidase which is in the chlorophyll synthesis pathway. The PPO inhibition starts a reaction in the cell that ultimately causes the destruction of cell membranes. The leaking cell membranes rapidly dry and disintegrate	Varied; including compounds having: slight toxicity (EPA category III); classified as a "not likely" human carcinogen, to: "likely to be a human carcinogen" (US-EPA, 2001).
2,4-D (phenoxyacetic herbicide)	Synthetic auxins ($O^{(4)}$)	Mimics a plant growth regulator. The specific mode of action is not well defined, however these herbicide mimic endogenous auxin (IAA) and appear to negatively affect cell wall plasticity and nucleic acid metabolism.	Critical effects include: hematologic, hepatic and renal toxicity. RfD of 1×10^{-2} mg/kg-day.

[a]Herbicide listed is one example of the herbicide family.
[b]Herbicide mode of action code according to the Herbicide Resistance Action Committee (HRAC, 2010) and the Weed Science Society of America (WSSA) classification (Senseman and Armbrust, 2007). The capitalized letter is the HRAC classification and the superscript number is the WSSA classification.
[c]The indicated herbicide mode of action is from the HRAC and WSSA descriptions as well as other citations.

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Appendix B

Tillage Systems

Below is an outline of general tillage and weed management practices for corn, soybean, and cotton. Tillage and weed control practices, however, vary greatly across regions of the United States and within a region based upon grower preference, soil texture, structure, and erosion potential for each individual farm.

Conventional or Conservation Tillage

Pre-tillage – may include shredding of cornstalks, usually in the fall, shortly after harvest.

Primary Tillage – types of equipment include moldboard plow, chisel plow, field cultivator, and tandem disk depending upon preference by the grower and soil erosion potential. For example, moldboard plow would be avoided if the fields are designated as Highly Erodible Land. Consequently, the chisel plow, field cultivator, or tandem disk are primary tillage implements in conservation tillage systems. Primary tillage can occur in the fall or the spring, depending on soil conditions and erosion potential of the soil. Furthermore, primary tillage may be done as a zone over the row where crops will ultimately be planted (strip tillage).

Secondary Tillage – types of equipment include tandem disk, field cultivator, chisel disk, disk harrow, harrow, and other implements. The type of equipment used depends on grower preferences, machinery complement, the region of the country, soil structure and texture, soil erosion potential, and environmental conditions during the season. Secondary tillage operations typically occur in the spring. Secondary tillage can involve multiple passes but quite often a series of implements are pulled in tandem, making it a one-pass operation. If growers are practicing conservation tillage, more than 30 percent of residue is present on the soil surface after planting.

Weed management – may or may not include a half rate or full rate of soil-applied herbicides with residual activity before or after planting (pre-emergence or early postemergence to the crop). Modern sprayers are typically 90 feet in width or more, and this step requires very little time and fuel use. Some growers, however, have tanks mounted on their planters and spray the residual herbicides at planting, thus saving an operation.

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Herbicide-resistant crops are typically treated with glyphosate postemergence to the crop and weeds and may include other herbicides with different mechanisms of action. A second (and possibly a third) application of glyphosate is typically applied, especially in cotton and soybean where additional applications may be made. If one or more weeds have become resistant to glyphosate or the farmer's herbicide of choice, then the grower may apply a substitute herbicide or use a tillage operation to control the weed.

Organic growers substitute tillage (cultivation) operations, typically three or more, for herbicides for weed control. The first operation is usually performed just after corn or soybean has emerged, using a rotary hoe. This step is usually followed by two cultivations, the first occurring when corn or soybean is quite small.

No Tillage

Pre-tillage – some growers may shred cornstalks.

Weed management – some growers will use a non-selective "burn-down" herbicide, such as glyphosate, to kill existing weeds if they are present before planting. Farmers may also wait until after planting for the initial herbicide application. This treatment may include a combination of herbicides that provide residual control of weeds that emerge later in the season. Postemergence applications of herbicides may be used later in the season depending on the weed infestation.

Planting – involves more sophisticated versions of the planters used for conventional tillage. Typically, the planters have heavy coulters and other attachments to clear the residue from the previous crop in the planting row. Not all soils are suitable for no-till, especially wet and heavy soils in northern latitudes, and no-till may lead to increased pest occurrence because conventional tillage may reduce insect, pathogen, and weed occurrence. On the other hand, no-till is well adapted to well-drained soils in warm regions because no-till improves soil-water infiltration and reduces soil evaporation, thereby providing more soil water to the crop.

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Appendix C

Biographical Sketches of Committee Members

David E. Ervin (*Chair*) is professor of environmental management, professor of economics, and fellow at the Center for Sustainable Processes and Practices at Portland State University. Dr. Ervin also serves on the board of the United States Society for Ecological Economics. He teaches economics of sustainability, business environmental management, and global environmental issues. His research and writing work includes university–industry research relationships in agricultural biotechnology, risk management of transgenic crops, voluntary business environmental management, and green technology. He recently directed a multi–university and multidisciplinary research project on public goods and university–industry relationships in agricultural biotechnology funded by the U.S. Department of Agriculture (USDA). He holds a B.S. and an M.S. from the Ohio State University and a Ph.D. in agricultural and resource economics from Oregon State University.

Yves Carrière is a professor of insect ecology in the Department of Entomology at the University of Arizona. He is an expert on the interactions between insects and transgenic plants, environmental impacts of transgenic crops, and integrated pest management. He is an associate editor of the *Journal of Insect Science.* Dr. Carrière received a B.Sc. and an M. Sc. in biology from Laval University and holds a Ph.D. in entomology and behavioral ecology from Simon Fraser University.

William J. Cox is a professor of crop science, joined the Cornell University faculty on an extension–research appointment in 1984. He has served in several capacities, including department associate chairman and extension leader. He recently evaluated the effects of transgenic seed on the yield and economics of corn production. His research also focuses on the environmental, biotic, and management interactions that influence the growth, development, yield, and quality of corn, soybeans, and wheat. He collaborates closely with soil scientists, animal scientists, plant pathologists, entomologists, and plant breeders in an effort to quantify whole-plant physiological responses of the crop to the environmental, biotic, and crop management interactions. He is a senior associate editor of the *Agronomy Journal* and the electronic publication *Crop Management*. Dr. Cox holds a Ph.D. in crop science from Oregon State University. He received an M.S. in agronomy from California State University-Fresno and a B.S. in history from the College of the Holy Cross.

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Jorge Fernandez-Cornejo is an agricultural economist in the Resource and Rural Economics Division of U.S. Department of Agriculture Economic Research Service (ERS). He currently works on the adoption and diffusion of agricultural technologies, agricultural biotechnology, and economics of biofuel production. Since joining ERS in 1990, Dr. Fernandez-Cornejo has researched U.S. farmers' experience with biotechnology in the first decade of its adoption and the effects of the technology on farmers' decision-making process. He has also studied the seed industry. He has a Ph.D. in operations research and agricultural economics and a master's in chemical engineering from the University of Delaware, an M.A. in energy and resources from the University of California, Berkeley, and a B.S. in industrial engineering. Dr. Fernandez-Cornejo has expertise in agricultural economics, farm management, integrated pest management, and farm-level impacts of transgenic seed.

Raymond A. Jussaume, Jr., is professor and chair of the Department of Community and Rural Sociology at Washington State University. His academic appointment includes teaching, extension–outreach and research. The main thrust of his research has been to contribute to a growing international research agenda on the globalization of agri-food systems and various strategies for improving agricultural sustainability. Most recently, much of his research has been focused on how agricultural sustainability can be enhanced by increasing the extent to which agri-food systems are "localized". He recently published several journal articles evaluating Washington State farmers' attitudes toward biotechnology. Dr. Jussaume was a participant at the National Research Council's Conference on Incorporating Science, Economics and Sociology in Developing Sanitary and Phytosanitary Standards in International Trade. He received his Ph.D. in development sociology from Cornell University.

Michele Marra is a professor of agricultural economics at North Carolina State University and an extension specialist. A production economist, she has concentrated on economic issues surrounding integrated pest management and the characteristics of agricultural innovations that affect farmer choice. She works on the farm-level impacts of crop biotechnologies and the economics of precision farming. Her recent publications have analyzed the benefits of and risks posed by adopting new agricultural technologies and the effects of agricultural biotechnology on farmer welfare. Dr. Marra is a member of the American Agricultural Economics Association and served as the associate editor of the *American Journal of Agricultural Economics* from 2004 to 2007. She has a Ph.D. in economics and an M.S. and a B.S. in agricultural economics from North Carolina State University.

Micheal Owen has a Ph.D. in agronomy and weed science from the University of Illinois. He is associate chair in the Department of Agronomy of Iowa State University. He has extensive expertise in weed dynamics, integrated pest management, and crop risk management. His objective in extension programming is to develop information about weed biology, ecology, and herbicides that can be used by growers to manage weeds with cost efficiency and environmental sensitivity. His work is focused on supporting management systems that emphasize a combination of alternative strategies and conventional technology. Dr. Owen has published extensively on farm-level attitudes toward transgenic crops and their impacts; selection pressure, herbicide resistance, and other weed life-history traits; and tillage practices.

Peter H. Raven is the president of the Missouri Botanical Garden; a George Engelmann Professor of Botany, Washington University, St. Louis; adjunct professor of biology, University

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of Missouri, St. Louis and St. Louis University; and a member of NAS. He earned his Ph.D. at the University of California, Los Angeles. Dr. Raven was a member of President Clinton's Council of Advisors on Science and Technology. He served for 12 years as home secretary of NAS and is a member of the academies of science of Argentina, Brazil, China, Denmark, India, Italy, Mexico, Russia, Sweden, and the U.K. Dr. Raven's primary research interests are in the systematics, evolution, and biogeography of the plant family Onagraceae; plant biogeography, particularly in the tropics and Southern Hemisphere; and tropical floristics and conservation. The author of numerous books and reports, both popular and scientific, Dr. Raven was a coauthor of *Biology of Plants* and *Environment*.

L. LaReesa Wolfenbarger conducts research on ecological effects of transgenic crops and agricultural practices, and on land management for grassland bird conservation at the University of Nebraska, Omaha. Other research interests include: the effects of agriculture on grassland ecosystems and the ecology of grassland ecosystems in agricultural landscapes. She has published several articles on the relationship between genetically engineered organisms and the environment and on the ecological risks and benefits related to genetically engineered plants. Her research also seeks to understand the responses of avian communities and reproduction to habitat variation and to management practices on restored grasslands, remnant prairies, and marginal agricultural habitats. Her other work includes synthesizing science on agricultural biotechnology, chairing a committee for a departmental graduate student program, organizing public symposia on environmental issues, and managing a 160-acre prairie preserve. Dr. Wolfenbarger earned her Ph.D. in ecology from Cornell University.

David Zilberman has been a professor in the Department of Agricultural and Resource Economics of the University of California, Berkeley, since 1979. His research interests are in agricultural and nutritional policy, economics of technological change, economics of natural resources, and microeconomic theory. He is a fellow of the American Agricultural Economics Association and the Association of Environmental and Resource Economists, which have recognized many of his publications on the adoption and regulation of agricultural biotechnology for their quality and value to the field. He received his B.A. in economics and statistics from Tel Aviv University in Israel and his Ph.D. in agricultural and resource economics from the University of California, Berkeley. Dr. Zilberman has expertise in the intersection of biotechnology and politics and economics and agricultural marketing. He has recently published on biofuels and biotechnology marketing.

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Simultaneous Adoption of Herbicide-Resistant and Conservation-Tillage Cotton Technologies

Roland K. Roberts, Burton C. English, Qi Gao, and James A. Larson

If adoption of herbicide-resistant seed and adoption of conservation-tillage practices are determined simultaneously, adoption of herbicide-resistant seed could indirectly reduce soil erosion and adoption of conservation-tillage practices could indirectly reduce residual herbicide use and increase farm profits. Our objective was to evaluate the relationship between these two technologies for Tennessee cotton production. Evidence from Bayes' theorem and a two-equation logit model suggested a simultaneous relationship. Mean elasticities for acres in herbicide-resistant seed with respect to the probability of adopting conservation-tillage practices and acres in conservation-tillage practices with respect to the probability of adopting herbicide-resistant seed were 1.74 and 0.24, respectively.

Key Words: Bayes' theorem, conservation tillage, cotton, genetically modified crops, herbicide-resistant crops, simultaneous logit model, technology adoption

JEL Classifications: Q12, Q16, Q24, O33

Herbicide-resistant BXN (Buctril-resistant) cotton seed was first introduced in 1995 by the Stoneville Pedigreed Seed Company (Ward et al. 1995) and Roundup-Ready cotton seed became commercially available in 1996 (Johnson 1996). The adoption of herbicide-resistant seed by farmers has dramatically changed cotton production practices with potential consequences for the environment. Monsanto claims that adoption of herbicide-resistant seed facilitates adoption of conservation tillage, which "sustains the environment." Soule, Tegene, and Wiebe used data from the 1996 USDA Agricultural Resource Management Survey (ARMS) and with logit analysis evaluated the effects of land tenure on adoption of conservation-tillage practices. Although data from the 1996 ARMS were available for adoption of herbicide-resistant crops (Fernandez-Cornejo and McBride 2002), adoption was low, and Soule, Tegene, and Wiebe were not intent on evaluating the synergy between adoption of herbide-resistant seed and conservation-tillage practices. Fernandez-Cornejo and McBride (2002) used 1997 ARMS data and a two-equation simultaneous probit model to evaluate this potential synergistic relationship. Contrary to Monsanto's claim, they found no evidence that soybean farmers who

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had adopted herbicide-resistant seed had a higher probability of adopting no-tillage practices than farmers who had not adopted herbicide-resistant seed. They found evidence supporting the converse, however; farmers who had adopted no-tillage practices had a higher probability of adopting herbicide-resistant soybean seed than farmers who had not adopted no-tillage practices. Lack of simultaneity most likely resulted from using cross-sectional data for the year after herbicide-resistant soybean seed was first introduced, leaving little time for adjustment in tillage practices. Using data from a 1999 survey of cotton farmers conducted in South Georgia, Ward et al. (2002) found evidence based on efficiency measures that farmers may have incentive to simultaneously adopt herbicide-resistant seed and conservation-tillage practices. Marra, Piggott, and Sydorovych found that 76% of North Carolina corn, soybean, and cotton acreage in herbicide-resistant seed was produced with conservation-tillage practices in 2001, while only 64% of corn, soybean, and cotton acreage in conventional seed was produced with conservation-tillage practices. Their specific results for cotton were different, with these two percentages being about the same at close to 73%.

Findings from the aforementioned cross-sectional analyses suggest a simultaneous relationship may exist between adoption of herbicide-resistant seed and adoption of conservation-tillage practices, but the evidence is inconclusive, especially for cotton. Sufficient annual time-series data are now available to investigate the relationship of the adoption of these two technologies over time. The Conservation Tillage Information Center (Fawcett and Towery) used a limited time-series sample of percentages of acres in glyphosate-resistant crops by tillage method for 1998 through 2000 and a 2001 survey by the American Soybean Association to suggest a simultaneous relationship between adoption of glyphosate-resistant crops and conservation-tillage practices in the United States. The information for Tennessee cotton acreage in Figure 1 (Doane Marketing Research, Inc.; Monsanto; Tennessee Department of Agriculture, 1996–2003, 2004) also suggests a relationship between adoption of herbicide-resistant seed and conservation-tillage practices. From 1992 through 1998, the share of Tennessee cotton acreage in conservation-tillage practices averaged 38% with no discernable trend. In 1999 when adoption of herbicide-resistant cotton seed started in earnest, the share of conservation-tillage acreage began a slight upturn to 40% with a dramatic increase thereafter, averaging 76% between 2000 and 2004 and reaching almost 100% in 2003 and 2004. During the 1992 through 2004 period, cotton acreage in Tennessee showed no perceptible trend, except during the mid-to-late 1990s when the Boll Weevil Eradication Program was active in middle and southwestern Tennessee (Suarez, Larson, and English 2000). Because of eradication program costs, farmers had an incentive to switch to other crops during the active phase of the program. Cotton acreage was relatively stable after 1998, when herbicide-resistant seed and conservation-tillage practices were being rapidly adopted.

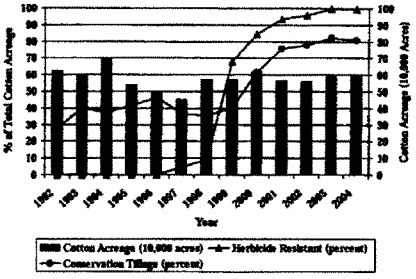


Figure 1. Total Tennessee cotton acreage with percentages in herbicide-resistant seed and conservation-tillage practices

In our research, annual time-series data along with Bayes' theorem and simultaneous estimation of two binomial logit models were used to examine the relationship between adoption of herbicide-resistant seed and adoption of conservation-tillage practices in Tennessee cotton production. If adoption of herbicide-resistant seed influenced adoption of conservation-tillage practices, adoption of herbicide-resistant seed may have indirectly led

to greater soil conservation and, if adoption of conservation-tillage practices influenced adoption of herbicide-resistant seed, adoption of conservation-tillage practices may have indirectly led to reduced residual herbicide use and increased farm profits as adoption of herbicide-resistant seed increased (Marra, Pardy, and Alston).

The choice of tillage method is a major decision for farmers because of its potential impacts on soil erosion and farm profit. Erosion of agricultural topsoils has been recognized as a problem for decades. Federal mandates have encouraged production practices to curb erosion. Anderson and Magleby and Heimlich provide a comprehensive overview of U.S. government policies designed to encourage conservation of our nation's topsoils. For example, Conservation Compliance, established in the 1985 Farm Bill, resulted in farms with highly erodible lands being required to alter cropping patterns and tillage practices to reduce erosion as a requirement for receiving government payments; in 1991, the Crop Residue Management Action Plan was developed to assist producers in implementing conservation systems. Tennessee has the most erodible cultivated cropland in the United States (Denton), with cotton being produced on some of those erodible soils. Adoption of conservation-tillage practices in cotton production has lagged behind adoption in other row crops (Tennessee Department of Agriculture 2004). Exploring the relationship between adoption of herbicide-resistant seed and adoption of conservation-tillage practices in Tennessee cotton production could lead to improved policies for reducing soil erosion.

Farmers who adopt conservation-tillage practices may benefit if adopting herbicide-resistant cotton seed allows them to use more effective herbicide treatment systems (Shoemaker et al.). Weed control is a vital component of conservation tillage. Failure to control weeds with conservation tillage can result in decreased quantity and quality of output. Besides preventing yield loss from weed competition, weed control is particularly important in cotton production because weeds can stain lint during harvest and processing, resulting in price discounts (Moore). Herbicide-resistant seed provides farmers with effective weed control programs that eliminate some problems associated with conservation programs (Fawcett and Towery). Investigating the relationship between adoption of conservation-tillage practices and herbicide-resistant seed could increase our understanding of ways to increase farm profit and reduce residual herbicide use (Marra, Pardey, and Alston) while conserving soil.

The objectives of this research were: (1) to evaluate the relationship between adoption of herbicide-resistant cotton seed and conservation-tillage cotton production practices over time and (2) to quantify the effects of economic phenomena on the adoption of herbicide-resistant seed and conservation-tillage practices for cotton production in Tennessee.

Methods and Data

The problem at hand is one of simultaneous adoption of synergistic technologies and management practices. Wu and Babcock used a polychotomous-choice selectivity model to evaluate choices among crop management plans, including tillage, rotation, and fertility management alternatives. Dorfman used a multinomial probit model, estimated in a Bayesian framework using Gibbs sampling (Geman and Geman), to evaluate adoption of improved irrigation methods and integrated pest management practices in apple production. Fernandez-Cornejo, Hendricks, and Mishra estimated a trivariate-choice selectivity model to evaluate the relationships among off-farm operator employment, off-farm spouse employment, and adoption of herbicide-resistant soybean seed. In an analysis more related to this article, Fernandez-Cornejo and McBride simultaneously estimated two binomial probit models for adoption of herbicide-resistant seed and no-tillage practices in soybean production.

Two methods were used to evaluate the relationship between adoption of herbicide-resistant cotton seed and conservation-tillage cotton production practices in Tennessee. The first method was a comparison of conditional

probabilities using Bayes' theorem (Render, Stair, and Hanna). The second was the simultaneous estimation of two binomial logit models, where the two equations represent the choices between adopting herbicide-resistant versus conventional seed and adopting conservation-tillage versus conventional tillage practices. Both methods assume the probability that a farmer will choose to produce an acre of cotton using a particular technology is equal to the share of cotton acreage produced with that technology.

Bayes' Theorem

Consider two events: (1) Event H occurs when an acre of Tennessee cotton is produced with herbicide-resistant seed and (2) Event C occurs when an acre of Tennessee cotton is produced with conservation-tillage practices. The complement of event H ($\bar{H}$) occurs when an acre is produced with conventional cotton seed and the complement of C ($\bar{C}$) occurs when an acre is produced with conventional tillage practices. Let the probability of an event occurring be represented by the share of total Tennessee cotton acreage in that event. When events H and C are not independent, Bayes' theorem states that the conditional probability of event H occurring given that event C has occurred, $P(H|C)$, is equal to the joint probability of events H and C occurring, $P(HC)$, divided by the marginal probability of event C occurring, $P(C)$, or mathematically (Render, Stair, and Hanna):

$$(1) \quad P(H|C) = \frac{P(HC)}{P(C)}.$$

If events H and C are independent, $P(H|C) = P(H)$ (Render, Stair, and Hanna). Bayes' theorem can be stated conversely as

$$(2) \quad P(C|H) = \frac{P(HC)}{P(H)},$$

where $P(C|H)$ is the conditional probability of event C occurring given that event H has occurred. If events H and C are independent, $P(C|H) = P(C)$.

Two other probabilities of interest are the conditional probability of one event occurring given that the complement of the other event has occurred

$$(3) \quad P(H|\bar{C}) = \frac{P(H\bar{C})}{P(\bar{C})} = \frac{P(H) - P(HC)}{1 - P(C)}, \text{ and}$$
$$P(C|\bar{H}) = \frac{P(\bar{H}C)}{P(\bar{H})} = \frac{P(C) - P(HC)}{1 - P(H)}.$$

When events H and C are independent, $P(H|\bar{C}) = P(H)$ and $P(C|\bar{H}) = P(C)$. Independence implies that the conditional probabilities in Equations (1) and (3) are equal, the conditional probabilities in Equations (2) and (4) are equal, and these conditional probabilities equal their respective marginal probabilities. Alternatively, if $P(H|C) > P(H|\bar{C})$, the adoption of conservation-tillage practices has increased the probability of adopting herbicide-resistant cotton seed, and if $P(C|H) > P(C|\bar{H})$, the adoption of herbicide-resistant seed has increased the probability of adopting conservation-tillage practices.

We calculated and compared the conditional probabilities in Equations (1) through (4) using data for 1998 through 2004 (Doane Marketing Research, Inc.) on the percentages of Tennessee cotton acres in herbicide-resistant seed, conservation-tillage practices, and in both technologies. This data set contained the only consistent time-series data found that included $P(C)$, $P(H)$, and $P(HC)$. Data were not available from Doane Marketing Research, Inc. for 1995 through 1997 and were excluded from the conditional probability analysis.

Logit Analysis

Following Garrod and Roberts, assume cotton production can be accomplished during a particular year using herbicide-resistant or conventional seed technologies and cotton acreage is constrained to a fixed level by exogenous or predetermined events (e.g., naïve price expectations and lagged cotton acreage). Let p_H and p_R represent average profit functions for herbicide-resistant and conventional seed technologies, respectively, where p_i is conditional upon the number of acres in technology i (q_i;

$i = H$ and $\bar{H}$), prices of outputs, and prices of inputs. Thus, we assume the farmer's problem is to allocate cotton acreage between herbicide-resistant and conventional seed technologies to achieve maximum profit. Our hypothesis is that adoption of herbicide-resistant seed is not independent of adoption of conservation-tillage practices. If they are not independent, p_i also includes conservation-tillage cotton acreage as an argument.

Assuming q_H and $q_{\bar{H}}$ are dependent on the conditional profits of both technologies, their quantities and shares can be defined as

$$(5) \quad q_i = f_i(p_H, p_{\bar{H}}, Q) \qquad i = H \text{ and } \bar{H}, \text{ and}$$
$$k_i = f_i \Big/ \sum_i f_i, \qquad i = H \text{ and } \bar{H},$$

where $k_H = q_H/Q$ and $k_H = q_H/Q$ are acreage shares of the respective technologies, which sum to one and are interpreted as probabilities of adopting the respective technologies. If we further assume

$$(6) \quad f_i = \exp[g_i(p_H, p_{\bar{H}}, Q)], \qquad i = H \text{ and } \bar{H},$$

then k_i is defined as a universal logit function (Amemiya). A convenient expression is then derived by taking the natural logarithm of the probability ratio, or odds ratio:

$$(7) \quad \ln(k_H/k_{\bar{H}}) = \ln(q_H/q_{\bar{H}}) = z_H = g_H - g_{\bar{H}}.$$

Equation (7) can be estimated using standard econometric methods if it is stochastic and linear in its arguments, and an estimate of the probability of adopting herbicide-resistant cotton seed can be obtained.

Conditional elasticities for q_H and $q_{\bar{H}}$ with respect to an explanatory variable can be calculated as in Roberts and Garrod. These elasticities, for variables other than Q, approach zero as k_i ($i = H$ or $\bar{H}$) approaches unity, suggesting that as the choice becomes limited to one alternative, that alternative cannot change in the short run because $q_i = Q$ is fixed. Also, the weighted sum of these two elasticities equals zero, where the weights are the acreage shares in each seed technology; thus, in the short run, cotton acreage in herbicide-tolerant seed cannot increase (or decrease) without decreasing (or increasing) acreage in conventional seed. For Q, the weighted sum of the elasticities is unity. If acreage in conservation-tillage practices is an argument of z_H, the influence of conservation-tillage adoption on the adoption of herbicide-tolerant seed, and its complement can be evaluated through their respective elasticities.

A similar model can be hypothesized for the choice between the use of conservation-tillage (C) and conventional tillage ($\bar{C}$) practices:

$$(8) \quad \ln(k_C/k_{\bar{C}}) = \ln(q_C/q_{\bar{C}}) = z_C = g_C - g_{\bar{C}},$$

where $k_j = q_j/Q$ ($j = C$ and $\bar{C}$); q_j is acreage in technology j ($j = C$ and $\bar{C}$); and $Q = q_c + q_{\bar{C}}$. We hypothesize that adoption of conservation-tillage practices is not independent of herbicide-resistant cotton seed adoption, suggesting that acreage in herbicide-resistant seed is an argument of z_C. If indeed acreage in conservation-tillage practices is an argument in Equation (7) and acreage in herbicide-resistant seed is an argument in Equation (8), these two equations form a system of simultaneous equations that must be estimated with appropriate econometric methods that account for simultaneity.

For empirical estimation, Equations (7) and (8) were specified as

$$(9) \quad \ln\left(\frac{HAC}{100 - HAC}\right) = \beta_0 + \beta_1 CAC + \beta_2 RUPR/COPR + \beta_3 RSPR/CSPR + \beta_4 D + \beta_5 CTAC + e_H,$$

and

$$(10) \quad \ln\left(\frac{CAC}{100 - CAC}\right) = \gamma_0 + \gamma_1 HAC + \gamma_2 RUPR/FUPR + \gamma_3 RAIN + \gamma_4 DRAIN + \gamma_5 NRAIN + \gamma_6 CTAC + e_C,$$

where variable definitions and means are given in Table 1 the βs and γs are parameters to be estimated; and e_H and e_C are random errors.

Table 1. Logit Model Variables, Definitions, and Means

Variable	Definition	Mean[a]
$\ln\left(\frac{HAC}{100 - HAC}\right)$	Natural logarithm of the ratio of the percentage of Tennessee cotton acres in herbicide-resistant seed (Roundup Ready, BXN, and Liberty Link, including stacked genes) to the percentage in conventional seed	1.80 (1.11)
$\ln\left(\frac{CAC}{100 - CAC}\right)$	Natural logarithm of the ratio of the percentage of Tennessee cotton acres in conservation tillage (no-till, ridge-till, strip-till, and mulch-till) to the percentage in conventional tillage	0.61 (0.20)
HAC	Percentage of Tennessee cotton acres in herbicide-resistant seed	69.31 (42.65)
CAC	Percentage of Tennessee cotton acres in conservation tillage	61.31 (52.58)
RUPR	Roundup price ($/pint)	5.83 (6.08)
COPR	Cotoran price ($/pint)	4.57 (4.93)
RUPR/COPR	Ratio of *RUPR* to *COPR*	1.28 (1.28)
RSPR	Roundup-Ready cotton seed price ($/lb)	1.88 (1.16)
CSPR	Conventional cotton seed price ($/lb)	1.01 (0.90)
RSPR/CSPR	Ratio of *RSPR* to *CSPR*	1.87 (1.15)
D	Dummy equals 1 for 1999 through 2004; 0 otherwise	0.75 (0.46)
CTAC	Total Tennessee cotton acres (100,000s)	5.52 (5.77)
FUPR	U.S. index of prices paid by farmers for fuel, 2002 = 1.00	1.07 (0.98)
RUPR/FUPR	Ratio of *RUPR* to *FUPR* lagged one period	6.35 (6.88)
RAIN	County average cumulative rainfall for April and May for the five highest cotton-producing counties in Tennessee (inches)	10.62 (9.96)
DRAIN	Dummy equals *RAIN* if *RAIN* is greater than one-half standard deviation above its mean (>11.16 inches); 0 otherwise	5.00 (3.08)
NRAIN	Dummy equals 1 if November rainfall in the previous year was greater than one-half standard deviation from its mean (>4.97 inches); 0 otherwise	0.38 (0.5)

[a] Means of annual data for 1997 through 2004, with means for 1992 through 2004 in parentheses.

Equations (9) and (10) were estimated with three-stage least squares using Tennessee annual time-series data for the 1992–2004 period. The Roundup price (*RUPR*) was taken from Economic Research Service (1997) and National Agricultural Statistics Service (2005, 2003, 2000, 1996a, 1996b). Cotoran (*COPR*), Roundup-Ready seed (*RSPR*), and conventional seed (*CSPR*) prices were taken from annual Tennessee field crop and cotton budgets (Johnson 1992–1993; Gerloff 1994–1999; Gerloff 2000–2004). The U.S. index of prices paid by farmers for fuel (*FUPR*) was taken from the Council of Economic Advisors. Data for the rainfall variables (*RAIN, DRAIN,* and *FRAIN*) were received from the National Climatic Data Center. The percentages of Tennessee cotton acreage in conservation-tillage (*CAC*) and conventional tillage (100-*CAC*), and total cotton acreage (*CTAC*) were found in Tennessee Department of Agriculture (1996–2003, 2004). Data used in the conditional probability analysis for the share of Tennessee cotton acreage in conservation-tillage practices provided by Doane Marketing Research, Inc. were not used for *CAC* because those tillage data only covered the 1998–2004 period. Tillage data from Tennessee Department of Agriculture allowed estimation of Equations (9) and (10) with time-series data for 1992 through 2004.

The *HAC* data for 1995 through 1997 were

not available from Doane. *HAC* was zero for 1992 through 1994 because herbicide-resistant cotton seed was not available to farmers in those years, and it was assumed zero for 1995 and 1996 because herbicide-resistant cotton seed adoption in Tennessee was sufficiently small (Alesii and Bradley, personal communication) for *HAC* to be considered zero without appreciably affecting the analysis. Data for *HAC* for 1998 through 2004 were received from Doane Marketing Research, Inc. Monsanto (Alesii and Bradley, personal communication) provided their best estimate for *HAC* in 1997 of about half the Doane 1998 level, which was used in the logit analysis. Acreage elasticities were calculated at the means of the data for 1997–2004 (instead of 1992–2004) to provide a more consistent view of acreage responsiveness during the period when herbicide-resistant seed was available and being adopted by farmers.

The price variables in Equations (9) and (10) were used as proxies for prices of inputs hypothesized to make the most difference in relative profitability for the respective technology choices. Other prices were not considered because of general colinearity among prices and to preserve degrees of freedom. Price ratios were used for similar reasons.

Prices of cotton lint produced with herbicide-resistant and conventional seed and with conservation and conventional tillage practices were not included in Equations (9) and (10) for two reasons. First, prices for cotton lint produced with the different technologies are not different unless these technologies produce lint of different qualities. Concern has been expressed about a potential loss in lint quality from herbicide-resistant seed (e.g., Bourland and Johnson; Coley; Ethridge and Hequet; Kerby et al.; Lewis; Verhalen, Greenhagen, and Thacker), although York et al. found no difference in lint quality compared with conventional cultivars in official North Carolina cultivar trails. Daniel et al. and Bauer and Busscher found no differences in lint quality among tillage systems. Even if differences in price discounts for lint quality existed, they would likely have little effect on the results because their magnitudes would be small relative to the magnitudes of the prices of lint produced with these technologies. Second, separate time-series data do not exist for prices of lint produced with the technologies evaluated in this analysis.

The expected lint price might still be included in Equations (9) and (10) if changes in the lint price changed the relative profitabilities for each technology choice because of differences in yields and/or production costs. Nevertheless, the expected lint price was excluded for five reasons. First, research suggests that lint yields are about the same for conservation and conventional tillage practices (e.g., Bradley, 1991, 1997; Bronson et al.; Buman et al.; Daniel et al.; Hudson; Keeling, Segarra, and Abernathy; York et al.). Second, differences in budgeted costs between no-tillage and conventional-tillage cotton in Tennessee were from 4% to 6% of total cost regardless of seed technology (Gerloff 2003), suggesting little potential for changes in relative profitabilities as the lint price changes. Third, although some evidence suggests lower lint yields from herbicide-resistant seed (Verhalen, Greenhagen, and Thacker), modeling by Fernandez-Cornejo and McBride (2000) indicated increased lint yields with adoption of herbicide-resistant seed, and Marra, Pardey, and Alston reported research that indicated herbicide-resistant lint yields between 120 lb/acre higher and 164 lb/acre lower than conventional seed yields. Other researchers who conducted field trials found similar yields between the two seed technologies (e.g., Goldman et al.; Keeling et al.; Vencill; York et al.). Fourth, differences in budgeted costs between Roundup Ready and conventional seed cotton were only about 1% of total cost regardless of tillage practice (Gerloff 2003), leaving little room for changes in relative profitabilities as the lint price changes. Fifth, even if the expected lint price affected the acreage allocation decisions in Equations (9) and (10), much of its influence would be transmitted to the decisions through *CTAC*. The expected lint price (among other things) determines *CTAC*, which in turn influences acreage-allocation decisions for the technology choices portrayed in Equations (9) and (10). Thus, the expected

lint price (e.g., lagged price) and *CTAC* would capture similar effects and be highly correlated, producing extreme multicollinearity.

Economic theory and other attributes of the variables in Equations (9) and (10) allowed formation of *a priori* hypotheses about the signs of the parameters. The motivating hypothesis for this research was that adoption of conservation-tillage practices positively influences adoption of herbicide-resistant cotton seed and that adoption of herbicide-resistant seed positively influences adoption of conservation-tillage practices; thus, β_1 and γ_1 were both expected to be positive, indicating that a change in the probability of adopting conservation-tillage cotton (*CAC*) positively influences the probability of adopting herbicide-resistant cotton seed and that a change in the probability of adopting herbicide-resistant cotton seed (*HAC*) positively influences the probability of adopting conservation-tillage practices.

Herbicide-resistant and conventional seed cotton use two distinct herbicide systems. As the cost of one system changes relative to the other, the relative profitability of herbicide-resistant and conventional seed cotton changes and the probability of a profit-maximizing farmer choosing one technology over the other changes. Roundup (*RUPR*) and Cotoran (*COPR*) prices were included in Equation (9) as proxies for the prices of herbicides used to produce herbicide-resistant and conventional seed cotton, respectively. The price of Roundup was chosen because herbicide-resistant cotton is produced almost entirely with Roundup-Ready seed and Roundup cannot be used over top of conventional seed cotton. The price of Cotoran was used because non-Roundup herbicides (e.g., Cotoran and others) are a small part of the cost of producing herbicide-resistant cotton, and Cotoran was a herbicide consistently recommended for conventional seed cotton in the University of Tennessee cotton budgets (Johnson 1992–1993; Gerloff 1994–1999; Gerloff 2000–2004). With Roundup being an input in the production of herbicide-resistant cotton, a change in *RUPR* was expected to negatively influence the probability of adopting herbicide-resistant cotton seed and positively influence the use of conventional cotton seed. Conversely, a change in *COPR* was expected to negatively influence the use of conventional cotton seed and positively influence the probability of adopting herbicide-resistant cotton seed; thus, β_2 was expected to be negative. Similarly, Roundup-Ready cotton seed and conventional cotton seed are inputs in the production of herbicide-resistant cotton and conventional seed cotton, respectively; therefore, β_3 was expected to be negative.

Although herbicide-resistant BXN (Buctril-resistant) cotton seed was first introduced in 1995 (Ward et al. 1995) and Roundup-Ready cotton seed became commercially available in 1996 (Johnson 1996), insufficient supply was available to meet farmer demand until 1999, when most farmers were able to purchase herbicide-resistant cotton seed if they wanted it. The binary variable *D* was included in Equation (9) to account for differences in years when sufficient herbicide-resistant seed was available to meet demand compared with years when herbicide-resistant seed was not available or not available in quantities sufficient to meet demand. Thus, β_4 was expected to be positive.

The sign of γ_2 was expected to be negative because herbicides are a more important input in the production of conservation-tillage cotton and fuel is a more important input in the production of conventional-tillage cotton. Roundup is a commonly used burn-down herbicide in conservation-tillage systems; hence its price was used as a proxy for prices of herbicides used in conservation-tillage systems. A decrease in the price of Roundup (*RUPR*) relative to the price of fuel (*FUPR*) would decrease the cost of producing conservation-tillage cotton relative to the cost of producing conventional-tillage cotton, encouraging farmers to move away from conventional-tillage towards conservation-tillage cotton production.

Conservation-tillage practices reduce the risk of late planting because fewer machinery operations are required and crops can generally be planted when conditions are too wet for conventional-tillage operations (Bates and Denton; Harper; Phillips and Hendrix). Heavy

Table 2. Adoption of Herbicide-Resistant and Conservation-Tillage Cotton for 1998–2004

Proportion of Tennessee Cotton Acreage	1998	1999	2000	2001	2002	2003	2004
Herbicide-resistant, $P(H)$	0.091	0.677	0.845	0.934	0.959	0.998	0.995
Conservation-tillage, $P(C)$	0.364	0.549	0.670	0.777	0.709	0.735	0.782
Herbicide-resistant and conservation-tillage, $P(HC)$	0.061	0.410	0.625	0.732	0.696	0.733	0.781

Source: Doane Marketing Research, Inc.

rainfall during April and May when farmers are engaged in tillage and planting operations makes timely tillage and planting more difficult, increasing the risk of late planting. Heavy spring rainfall was hypothesized to encourage cotton farmers to rent no-till planting equipment, custom hire no-till planting operations, or retrofit their conventional planters for no-till planting (Bradley 2001). Conversely, light spring rainfall might encourage farmers to engage in what some call "recreational tillage" because many farmers feel they should be out working in the field when the weather is good (e.g., Alesii and Bradley, personal communication; Delta Farm Press; Fletcher). The latter occurs because farmers who are affected by heavy spring rainfall are at the margin of conservation-tillage adoption and seldom convert completely by selling their tillage equipment (Dumler). These marginal adopters can bring their tillage equipment back online when the weather is good if they have doubts about the relative profitabilities of the two tillage practices. Therefore, γ_3 was expected to be positive. A positive γ_3 implies that increases in rainfall encourage adoption of conservation-tillage practices by the same amount as decreases in rainfall encourage abandonment of conservation-tillage practices. *DRAIN* was included in Equation (10) to test the hypothesis that April and May rainfall of more than one-half standard deviation above its mean has a different effect on adoption of conservation-tillage practices than rainfall of lesser amounts; thus, γ_4 was expected to be positive.

Heavy rainfall in the previous year (*NRAIN*) may have a different effect on tillage decisions than heavy spring rainfall. It may cause farmers to rut their fields during harvest, requiring spring tillage; thus, the sign of γ_5 would be negative. Alternatively, heavy rainfall in the fall may cause farmers to look toward future spring tillage operations and begin planning for conversion to conservation tillage to avoid a perceived risk of late planting. If farmers apply past heavy rainfall to their tillage decisions in this way, γ_5 would be positive; thus, the sign of γ_5 was ambiguous.

Theoretically, cotton is produced on the "best" cotton land in terms of potential profit compared with other crops. Consequently, changes in cotton acreage would typically occur on marginal cotton land that may be more erodible than land that is already in cotton production. We hypothesized that farmers are more likely to use conservation-tillage practices on this marginal land than on the less-erodible land already in cotton production; thus, γ_6 was expected to be positive. Farmers who increase cotton acreage or who produce cotton for the first time may be less risk averse than those who do not, and they may be more willing to adopt new technologies. If this hypothesis were correct, β_5 would be positive, and the positive expectation for γ_6 would be reinforced.

Results

Bayes' Theorem

Shares of Tennessee cotton acreage produced with each technology and with both technologies for 1998 through 2004 are presented in Table 2 and the conditional probabilities in Equations (1) through (4) are presented in Table 3. In all years except in 2003, the conditional probability of using herbicide-resistant seed given conservation-tillage practices, $P(H|C)$, is greater than the conditional prob-

Table 3. Conditional Probabilities Showing the Relationships Between Adoption of Herbicide-Resistant Cotton Seed and Conservation-Tillage Cotton Production Practices, 1998–2004

Conditional Probability	1998	1999	2000	2001	2002	2003	2004
$P(H\|C)$	0.169	0.747	0.932	0.968	0.981	0.997	0.999
$P(H\|\bar{C})$	0.047	0.593	0.668	0.817	0.905	1.000	0.981
$P(C\|H)$	0.674	0.605	0.740	0.805	0.726	0.735	0.785
$P(C\|\bar{H})$	0.333	0.431	0.294	0.377	0.331	1.000	0.143

[a] $P(H|C)$ and $P(H|\bar{C})$ are conditional probabilities of a Tennessee cotton acre being produced with herbicide-resistant seed (H) given that it is produced with conservation-tillage practices (C) or conventional-tillage practices ($\bar{C}$), respectively. $P(C|H)$ and $P(C|\bar{H})$ are conditional probabilities of a Tennessee cotton acre being produced with C given that it is produced with H or conventional cotton seed ($\bar{H}$), respectively.

ability of using herbicide-resistant seed given conventional tillage practices, $P(H|\bar{C})$, which indicates that cotton farmers who had adopted conservation-tillage practices had a higher probability of adopting herbicide-resistant cotton seed than those farmers who had not adopted conservation-tillage practices. This finding suggests that diffusion of herbicide-resistant seed technology was faster among farmers who used conservation-tillage practices than among those who did not. Also, the gap between $P(H|C)$ and $P(H|\bar{C})$ narrows over time, and in 2003 and 2004 these conditional probabilities are almost equal to each other and equal to the marginal probability of adopting herbicide-resistant seed ($P(H)$ in Table 2), suggesting that differences in tillage practices had less influence on the probability of adopting herbicide-resistant seed in later years because almost all Tennessee cotton acreage was in herbicide-resistant seed in 2003 and 2004 regardless of tillage method.

Results also suggest that adoption of herbicide-resistant cotton seed influenced the probability of adopting conservation-tillage practices as indicated by $P(C|H)$ being greater than $P(C|\bar{H})$ every year except 2003 (Table 3). In this case, however, the gap between the two conditional probabilities does not narrow over time, indicating that adoption of herbicide-resistant seed continued to have an influence through time on the probability of adopting conservation-tillage practices. The conditional probability of 1 in 2003 resulted from only 1,088 Tennessee cotton acres being produced with conventional cotton seed in that year, all of which were produced with conservation-tillage practices.

The Bayes' results suggest a simultaneous relationship between adoption of herbicide-resistant cotton seed and adoption of conservation-tillage practices. These results bode well for the simultaneity hypothesis in the logit analysis.

Logit Analysis

Results from the simultaneous logit model estimated with three-stage least squares are presented in Table 4. All coefficients but one have their hypothesized signs and the high system weighted-average R^2 (0.95) suggests a good fit to the data. Multicollinearity diagnostics (Belsley, Kuh, and Welsch) indicated collinearity between the intercept and *CTAC* in both equations. Thus, multicollinearity may have seriously degraded the standard errors of the coefficients for *CTAC*, rendering the results from hypothesis testing inconclusive for those coefficients (Belsley, Kuh, and Welsch).

Results from the estimation of Equation (9) in Table 4 suggest that the probability of adopting conservation-tillage practices (*CAC*) significantly influenced the probability of adopting herbicide-resistant cotton seed and results from the estimation of Equation (10) indicate that the probability of adopting herbicide-resistant seed (*HAC*) significantly influenced the probability of adopting conservation-tillage practices for Tennessee cotton production. As suggested by the conditional probability results in Table 3 and the 1997–

Table 4. Three-Stage Least Squares Regression and Elasticities for Cotton Acreage Logit Model

Herbicide-Resistant Seed, Equation (9)			Conservation-Tillage Practices, Equation (10)		
Variable[a]	Parameter Estimate	Elasticity[b]	Variable[a]	Parameter Estimate	Elasticity[b]
INTERCEPT	0.586 (5.545)[c]		*INTERCEPT*	−2.071 (1.344)	
CAC	0.092*** (0.027)	1.74[d] [−3.92]	*HAC*	0.009*** (0.002)	0.24[e] [−0.38]
RSPR/CSPR	−1.258 (1.231)	−0.50 [1.12]	*RUPR/FUPR*	−0.148* (0.062)	−0.36 [0.57]
	−1.353* (0.650)	−0.78 [1.75]	*RAIN*	0.111** (0.042)	0.46 [−0.72]
D	2.601* (1.392)	0.60 [−1.35]	*DRAIN*	0.023 (0.026)	0.55[f] [−0.87]
			NRAIN	0.558* (0.238)	0.11 (−0.17)
CTAC	−0.410 (0.767)	0.31 [2.57]	*CTAC*	0.232 (0.161)	1.56 [0.11]
System-weighted R^2		0.95	System degrees of freedom		13

[a] Variables are defined in Table 1.
[b] Elasticities are calculated at the 1997–2004 means of the variables.
[c] Numbers in parentheses are asymptotic standard errors.
[d] Percentage change in cotton acres in herbicide-resistant seed for a 1% change in the variable in the row. Elasticities in brackets are for conventional seed.
[e] Percentage change in the number of cotton acres in conservation-tillage practices for a 1% change in the variable in the row. Elasticities in brackets are for conventional-tillage practices.
[f] Elasticities calculated using the sum of the coefficients for RAIN and DRAIN at the mean of RAIN.
*, **, *** Significantly different from zero at the 10%, 5%, and 1% levels, respectively.

2004 mean elasticities in Table 4, these influences are not symmetric. While both elasticities are positive, the number of cotton acres in herbicide-resistant seed increases (decreases) by 1.74% for a 1% increase (decrease) in the probability of adopting conservation-tillage practices (*CAC*), while the number of cotton acres in conservation-tillage practices increases (decreases) by only 0.24% for a 1% increase (decrease) in the probability of adopting herbicide-resistant seed (*HAC*).

Results for Equation 9 (Table 4) also indicate that the short-run supply of Tennessee cotton acreage in herbicide-resistant seed increases (decreases) by 0.78% when the Roundup Ready cotton seed price decreases (increases) by 1% relative to the conventional cotton seed price (*RSPR/CSPR*) and that the probability of adopting herbicide-resistant seed was higher during the 1999–2004 period than in earlier years when it was not available, or before sufficient supply of herbicide-resistant seed was produced to meet demand, as evidenced by the positive coefficient for D.

Findings from Equation (10) suggest that the short-run supply of Tennessee cotton acreage in conservation-tillage increases (decreases) by 0.36% when the price of Roundup decreases (increases) by 1% relative to the price of fuel (*RUPR/FUPR*) (Table 4). In addition, the finding that the coefficient for *RAIN* is statistically significant, while the coefficient for *DRAIN* is not, suggests that symmetry exists in cotton farmers' response to increases or decreases in spring rainfall. The elasticity for *RAIN* indicates that conservation-tillage cotton acreage increases by 0.46% when spring rainfall increases by 1% and it decreases by the same amount when rainfall decreases by 1%, other things remaining constant. The positive coefficient for *NRAIN* suggests that heavy rainfall in the fall of the previous year increases the probability that cotton farmers will adopt conservation-tillage practices in the spring.

Conclusions

Results suggest that the introduction of herbicide-resistant cotton seed in Tennessee increased the probability that farmers would adopt conservation-tillage practices. Along with the direct benefits of increased profit potential and the substitution of nonresidual herbicides for residual herbicides, the introduction of herbicide-resistant cotton seed indirectly contributed to increased conservation of Tennessee soils. This indirect environmental benefit of reduced soil erosion should not be ignored when considering the costs and benefits of herbicide-resistant cotton production. Also, farmers who had previously adopted conservation-tillage practices were more likely to adopt herbicide-resistant cotton seed, indirectly reducing their use of residual herbicides and increasing their profit potential as they reduced erosion. Thus, the synergistic relationship between adoption of herbicide-resistant cotton seed and adoption of conservation-tillage practices for cotton production likely contributed to reduced soil erosion, reduced residual herbicide use, and increased profit during a period of low cotton prices.

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The Economics of Genetically Modified Crops

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Key Words

agricultural biotechnology, consumer acceptance, impacts, regulation, technology adoption

Abstract

Genetically modified (GM) crops have been used commercially for more than 10 years. Available impact studies of insect-resistant and herbicide-tolerant crops show that these technologies are beneficial to farmers and consumers, producing large aggregate welfare gains as well as positive effects for the environment and human health. The advantages of future applications could even be much bigger. Given a conducive institutional framework, GM crops can contribute significantly to global food security and poverty reduction. Nonetheless, widespread public reservations have led to a complex system of regulations. Overregulation has become a real threat for the further development and use of GM crops. The costs in terms of foregone benefits may be large, especially for developing countries. Economics research has an important role to play in designing efficient regulatory mechanisms and agricultural innovation systems.

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1. INTRODUCTION

A genetically modified (GM) crop is a plant used for agricultural purposes into which one or several genes coding for desirable traits have been inserted through the process of genetic engineering. These genes may stem not only from the same or other plant species, but also from organisms totally unrelated to the recipient crop. The basic techniques of plant genetic engineering were developed in the early 1980s, and the first GM crops became commercially available in the mid-1990s. Since then, GM crop adoption has increased rapidly. In 2008, GM crops were being grown on 9% of the global arable land (James 2008).

The crop traits targeted through genetic engineering are not completely different from those pursued by conventional breeding. However, because genetic engineering allows for the direct gene transfer across species boundaries, some traits that were previously difficult or impossible to breed can now be developed with relative ease. Three categories of GM traits can be distinguished: First-generation GM crops involve improvements in agronomic traits, such as better resistance to pests and diseases. Second-generation GM crops involve enhanced quality traits, such as higher nutrient contents of food products. Third-generation crops are plants designed to produce special substances for pharmaceutical or industrial purposes.

The potentials of GM crops are manifold. Against the background of a dwindling natural resource base, productivity increases in global agriculture are important to ensure sufficient availability of food and other raw materials for a growing population (von Braun 2007). GM crops can also bring about environmental benefits. Furthermore, new seed technologies have, in the past, played an important role for rural income growth and poverty alleviation in developing countries (e.g., Hazell & Ramasamy 1991, Fan et al. 2005). These effects are also expected for GM crops (FAO 2004). Finally, nutritionally enhanced crops could help improve the health status of consumers (e.g., Bouis 2007, Unnevehr et al. 2007).

In spite of these potentials, the development and use of GM crops have aroused significant opposition. Public reservations are particularly strong in Europe, but they have also spilled over to other countries and regions through trade regulations, public media, and outreach efforts of antibiotech lobbying groups (e.g., Pinstrup-Andersen & Schioler 2001, Miller & Conko 2004, Herring 2007, Paarlberg 2008). The major concerns are related to potential environmental and health risks, but there are also fears about adverse social implications (e.g., Altieri 2001, Friends of the Earth 2008). For instance, some believe that GM technology could undermine traditional knowledge systems in developing countries. Given the increasing privatization of crop improvement research and proliferation of intellectual property rights (IPRs), there are also concerns about the potential monopolization of seed markets and exploitation of smallholder farmers (e.g., Sharma 2004).

Because GM crops are associated with new potentials and issues, their emergence has also triggered substantial research dealing with economic and policy aspects. This article reviews the available research on the economics of GM crops. Section 2 gives a brief overview of the status of commercialized GM crops and expected trends for the future. Then, work related to the analysis of impacts at the micro and macro level is discussed. Whereas Sections 3 and 4 address impacts of first-generation GM applications, Section 5 refers to second-generation crops from an ex ante perspective. Sections 6 and 7 focus on consumer acceptance and the economics of regulation, including aspects of biosafety as

well as food labeling and IPRs. In the concluding section, policy and research implications are discussed.

2. STATUS OF GM CROPS

2.1. Commercialized GM Crops

The commercial application of GM crops began in the mid-1990s. Since then, the technology has spread rapidly around the world, both in industrialized and developing countries (**Figure 1**). In 2008, GM crops were being grown on 125 million ha in 25 countries. The countries with the biggest share of the GM crop area were the United States (50%), Argentina (17%), Brazil (13%), India (6%), Canada (6%), and China (3%) (James 2008). Strikingly, among the countries of the European Union (EU), only Spain grows GM crops on a significant scale. Although a few other EU countries have approved individual GM technologies, the commercial area is still negligible, because of public-acceptance problems and unfavorable regulatory frameworks.

In spite of the widespread international use of GM crops, the portfolio of available crop-trait combinations is still very limited. At present, only a few first-generation technologies have been commercialized. The dominant technology is herbicide tolerance (HT) in soybeans, which made up 53% of the global GM crop area in 2008. HT soybeans are currently grown mostly in the United States, Argentina, Brazil, and other South American countries. This technology accounts for 70% of worldwide soybean production.

GM maize is the second-most dominant crop and covered 30% of the global GM area and 24% of total maize production in 2008 (James 2008). GM maize involves HT and insect resistance, partly as separate and partly also as stacked technologies. Insect resistance is based on different genes from the soil bacterium *Bacillus thuringiensis* (Bt). These Bt genes control the European corn borer, the corn rootworm, and different stemborers (Romeis et al. 2008). Bt maize is grown mostly in North and South America, but it is also planted to a significant extent in South Africa and the Philippines.

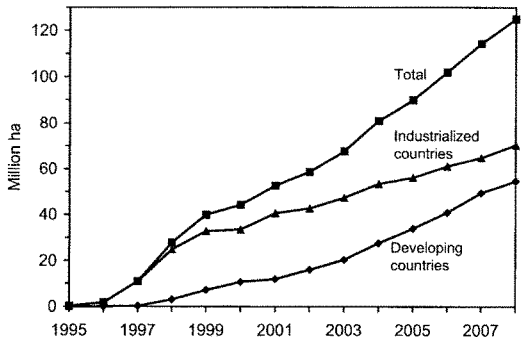


Figure 1

Development of the global area using genetically modified crops (1995–2008).
Source: James (2008).

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GM crops with significant area shares also include cotton and canola. Bt cotton with resistance to bollworms and budworms is particularly relevant in developing countries. In 2008, India had the largest Bt cotton area with 7.6 million ha, followed by China with 3.8 million ha. South Africa, Argentina, Mexico, and a few other countries use this technology as well. In the United States, Bt and HT cotton are employed, partly with stacked genes. Until now, HT canola was grown mostly in Canada and the United States. A few other GM crops, including HT alfalfa and sugarbeet as well as virus-resistant papaya and squash, have been approved in individual countries, so far covering only relatively small areas.

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2.2. GM Crops in the Pipeline

A couple of GM technologies previously developed for food crops either were never commercialized or were withdrawn from the market because of consumer-acceptance and marketing problems. Examples include Bt and virus-resistant potato as well as HT wheat. Yet, such technologies may be reintroduced, should public acceptance improve. A number of other GM crop technologies that provide insect resistance or HT are ready to be commercialized. For instance, Bt rice has been field tested extensively in China and other countries (Huang et al. 2005, Cohen et al. 2008). Different Bt vegetables—including eggplant, cauliflower, and cabbage—are likely to be commercialized soon in India and other countries in Asia and Africa (Krishna & Qaim 2007, Shelton et al. 2008). HT rice is also in a relatively advanced phase within the research and development (R&D) pipeline (Hareau et al. 2006).

Other first-generation GM technologies that are being developed include fungal, bacterial, and virus resistance in major cereal as well as root and tuber crops (Halford 2006). Their market introduction can be expected in the short to medium run. Plant tolerance to abiotic stress—such as drought, heat, and salt—is also being worked on intensively. Yet, because the underlying genetic mechanisms are complex, the work is at a more basic level, so significant commercial releases can be expected only in the medium run (Herdt 2006, Ramasamy et al. 2007).

Second-generation GM technologies in the pipeline include product quality improvements for nutrition and industrial purposes. Examples are oilseeds with improved fatty acid profiles; high-amylose maize; staple foods with enhanced contents of essential amino acids, minerals, and vitamins; and GM functional foods with diverse health benefits (Jefferson-Moore & Traxler 2005, Pew Initiative on Food and Biotechnology 2007).

Enhancing food crops with higher nutrient contents through conventional or GM breeding is also called biofortification. A well-known example of a GM biofortified crop is Golden Rice, which contains significant amounts of provitamin A. Golden Rice could become commercially available in some Asian countries by 2012 (Stein et al. 2006, Potrykus 2008). Other biofortification projects include the development of GM sorghum, cassava, banana, and rice enhanced with multiple nutrients (Qaim et al. 2007). Such crops may become commercially available over the next 5–10 years.

Third-generation GM crops involve molecular farming where the crop is used to produce either pharmaceuticals such as monoclonal antibodies and vaccines or industrial products such as enzymes and biodegradable plastics (Moschini 2006, Halford 2006). Although concepts have been proven for a number of these technologies, product development and regulatory aspects are even more complex than they are for first- and second-

generation crops. Substances produced in the plants must be guaranteed not to enter the regular food chain with a zero-tolerance threshold. Therefore, plants that are not used for food and feed purposes will likely be chosen for product development, or approvals for third-generation GM crops will be given for use under contained conditions only. In either case, this brief overview reveals that the GM crops available so far represent only a very small fraction of the large future potentials of plant genetic engineering.

3. MICROLEVEL IMPACTS OF FIRST-GENERATION GM CROPS

Because HT and insect-resistant Bt crops have already been used for a number of years, numerous microlevel impact studies have been carried out in different countries. Many such studies are based on random sample surveys, comparing the performance of adopters and nonadopters of GM crops (Kalaitzandonakes 2003, Naseem & Pray 2004, Qaim 2005, Gandhi & Namboodiri 2006). However, such with-without comparisons can be associated with a selectivity bias. On the one hand, if adopting farmers are more skillful than their nonadopting counterparts, the net technological impacts may be overestimated, because the group of adopters may show better performance even without GM technology. On the other hand, if the technology is adopted only by farmers under specific conditions, net impacts may be underestimated. For instance, Bt technology is expected to be particularly beneficial in high pest pressure environments. Therefore, simply comparing the productivity of adopters in high pest pressure environments with that of nonadopters in low pest pressure environments would lead to a downward bias in impact assessment.

Different approaches have been used to reduce a potential selectivity bias. For instance, some authors have observed developments over time, involving several rounds of data collection (e.g., Pray et al. 2002, Sadashivappa & Qaim 2009). Others have combined survey data of GM farmers with calculations of what would have been without technology adoption (e.g., Gianessi et al. 2002, Brookes & Barfoot 2008). In addition, within-farm comparisons have been made in situations where adopting farmers continued to use conventional crops on part of their land (e.g., Qaim & de Janvry 2005). Econometric approaches to deal with selectivity issues are explained below.

3.1. Farm-Level Impacts of HT Crops

HT crops are tolerant to certain broad-spectrum herbicides such as glyphosate and glufosinate, which are more effective, less toxic, and usually cheaper than selective herbicides. Accordingly, farmers who adopt HT technology benefit in terms of lower herbicide expenditures. Total herbicide quantities applied were reduced in some situations, but not in others. In Argentina, herbicide quantities were increased significantly (Qaim & Traxler 2005), in large part owing to the fact that herbicide sprays were substituted for tillage. In Argentina, the share of soybean farmers using no-till doubled to almost 90% since the introduction of HT technology (Trigo & Cap 2006), whereas in the United States and Canada, no-till practices expanded through HT adoption (Kalaitzandonakes 2003, Fernandez-Cornejo & Caswell 2006). In terms of the yields achieved, no significant difference between HT and conventional crops is seen in most cases. Only in a few examples when certain weeds were difficult to control with selective herbicides did the adoption of HT and the switch to broad-spectrum herbicides result in better weed control and higher crop

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yields. These include HT soybeans in Romania and HT maize in Argentina (Brookes & Barfoot 2008).

Overall, HT technology reduces the cost of production through lower expenditures for herbicides, labor, machinery, and fuel. Yet, because HT crops were developed and commercialized by private companies, a technology fee is charged on seeds, which varies among crops as well as countries. Several early studies for HT soybeans in the United States showed that the fee was of a similar magnitude or sometimes higher than the average cost reduction, so that gross margin effects were small or partly negative (e.g., Duffy 2001, Fernandez-Cornejo et al. 2002). Comparable results were also obtained for HT cotton and HT canola in the United States and Canada (Fulton & Keyowski 1999, Marra et al. 2002, Phillips 2003, Naseem & Pray 2004). The main reasons for farmers in such situations to continue using HT technologies were easier weed control and savings in terms of management time. Fernandez-Cornejo et al. (2005) showed that the saved management time for U.S. soybean farmers translated in part into higher off-farm incomes. Moreover, farmers are heterogeneous, such that many adopters have benefited in spite of zero or negative mean gross margin effects. The average farm-level profits seem to increase over time, partly as a result of seed-price adjustments and farmer-learning effects.

In South American countries, the average gross margin effects of HT crops, especially HT soybeans, are larger than in North America (Trigo & Cap 2006). While the agronomic advantages are similar, the fee charged on seeds is lower, as HT technology is not patented there. Many soybean farmers in South America use farm-saved GM seeds. Qaim & Traxler (2005) showed that the average gross margin gains through HT soybean adoption are in a magnitude of more than $20 per ha for Argentina.

3.2. Farm-Level Impacts of Bt Crops

Insect-resistant Bt crops have different effects than do HT crops. Bt crops produce proteins that are toxic to larvae of some lepidopteran and coleopteran insect species. Therefore, Bt is a pest-control agent that can be used as a substitute for chemical insecticides. Following Lichtenberg & Zilberman (1986) and Zilberman et al. (2004), this can be expressed in a damage-control framework:

$$Y = F(x)[1 - D(z, Bt; N)],$$

where Y is the effective crop yield, and $F(\cdot)$is potential yield without insect damage, which depends on variable inputs, x. $D(\cdot)$is the damage function determining the fraction of potential output being lost to insect pests; it can take values in the 0–1 interval. Crop losses depend on exogenous pest pressure, N, and they can be reduced through the application of chemical insecticides, z, and/or the use of Bt technology. If pest pressure is high and farmers use a lot of chemical insecticides in the conventional crop, Bt adoption should lead to substantial insecticide reductions.[1] However, Bt technology can also impact effective crop yields. Even though the Bt gene does not affect potential yield, $F(\cdot)$, it can lead to a reduction in crop losses, $D(\cdot)$, when there is previously uncontrolled pest damage, thus leading to a higher Y.

[1]Pemsl et al. (2008) pointed out that natural pest-control agents such as beneficial insects could also reduce crop losses but that these are often suppressed through chemical insecticides. Therefore, even without Bt, a reduction in chemical insecticides may be possible in specific situations. However, compared with chemical insecticides, Bt is much less harmful to beneficial insects (Shelton et al. 2009).

Insecticide reduction and yield effects are closely related: Farmers who use small amounts of insecticides in their conventional crop in spite of high pest pressure will realize a sizeable yield effect through Bt adoption, whereas the insecticide reduction effect will dominate in situations when farmers initially use higher amounts of chemical inputs. The same principles also hold for other pest-resistant GM crops. In general, yield effects will be more pronounced in developing rather than in developed countries, because pest pressure is often higher in the tropics and subtropics and resource-poor farmers face more severe constraints in chemical pest control (Qaim & Zilberman 2003).

3.2.1. Empirical evidence. The Bt-insecticide-yield linkages are diagrammed in **Figure 2** using field trial data with Bt cotton in India. As shown, Bt does not completely eliminate the need for insecticide sprays because some crop damage still occurs when the technology is used. The reason is that Bt toxins are very specific to certain pest species, whereas other insect pests, especially sucking pests, remain unaffected.

What do the agronomic impacts look like under practical farmer conditions? **Table 1** confirms that both insecticide-reducing and yield-increasing effects can be observed internationally. Yield effects of Bt cotton are highest in Argentina and India. For Argentina, the explanation is simple: Conventional cotton farmers underutilize chemical insecticides, so that insect pests are not effectively controlled (Qaim & de Janvry 2005). In India, however, insecticide use in conventional cotton is much higher (Qaim et al. 2006). This suggests that factors other than insecticide quantity influence damage control in conventional cotton and, thus, the yield effects of Bt technology. These factors include insecticide quality, insecticide resistance, and the correct choice of products and timing of sprays.

For Bt maize, similar effects are observable, albeit generally at a lower magnitude (**Table 1**). Except for Spain, where the percentage reduction in insecticide use is large, the more important result of the use of Bt maize is an increase in effective yields. In the United States, for instance, Bt maize is used mainly against the European corn borer, which is not

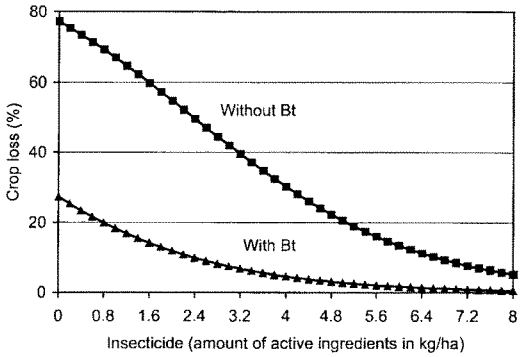


Figure 2

Relationship between insecticide use and cotton crop losses with and without Bt in India.
Source: Qaim & Zilberman (2003).

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Table 1 Average farm-level agronomic and economic effects of Bt crops

Country	Insecticide reduction (%)	Increase in effective yield (%)	Increase in gross margin (US$/ha)	Reference(s)
Bt cotton				
Argentina	47	33	23	Qaim & de Janvry 2003, 2005
Australia	48	0	66	Fitt 2003
China	65	24	470	Pray et al. 2002
India	41	37	135	Qaim et al. 2006, Sadashivappa & Qaim 2009
Mexico	77	9	295	Traxler et al. 2003
South Africa	33	22	91	Thirtle et al. 2003, Gouse et al. 2004
United States	36	10	58	Falck-Zepeda et al. 2000b, Carpenter et al. 2002
Bt maize				
Argentina	0	9	20	Brookes & Barfoot 2005
Philippines	5	34	53	Brookes & Barfoot 2005, Yorobe & Quicoy 2006
South Africa	10	11	42	Brookes & Barfoot 2005, Gouse et al. 2006
Spain	63	6	70	Gómez-Barbero et al. 2008
United States	8	5	12	Naseem & Pray 2004, Fernandez-Cornejo & Li 2005

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often controlled by chemical means (Carpenter et al. 2002).[2] In Argentina and South Africa, mean yield effects are higher because pest pressure is more severe than it is in temperate climates. The average yield gain of 11% shown in **Table 1** for South Africa refers to large commercial farms. These farms have been growing yellow Bt maize hybrids for several years. Gouse et al. (2006) analyzed on-farm trials that were carried out with smallholder farmers and white Bt maize hybrids in South Africa. They found average yield gains of 32% on Bt plots. In the Philippines, average yield advantages are 34%.

Preliminary evidence based on field-trial observations also exists for other Bt crops. Huang et al. (2005) observed high insecticide reductions but relatively small yield effects for Bt rice in China, whereas Krishna & Qaim (2008b) reported significant insecticide and yield effects for Bt eggplant in India.

[2]More recently, a different Bt maize technology has been commercialized in the United States to control the corn rootworm complex, against which significant amounts of chemical insecticides are used in conventional agriculture. However, representative studies on the impacts of this new Bt maize technology under farmer conditions are not available.

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3.2.2. Econometric estimates. Econometric analyses with different model specifications confirm the net insecticide-reducing and yield-increasing effects of Bt technology. For Bt maize, Fernandez-Cornejo & Li (2005) provided estimates for the United States, and Yorobe & Quicoy (2006) did so for the Philippines. More studies are available for Bt cotton: Huang et al. (2002a) employed an insecticide-use model and a production function with a damage-control specification to estimate the effects in China. A similar analysis was done by Qaim & de Janvry (2005) in Argentina. Bennett et al. (2006) estimated Cobb-Douglas-type production functions for a sample of farmers in India.

Qaim et al. (2006) also estimated productivity effects of Bt cotton in India, differentiating between Bt gene and germplasm effects. They showed that part of the impact variability observed in India during the first years of adoption was due to the incorporation of the Bt gene in only a few cotton varieties that were not suitable for all locations. In such situations, a yield drift can be observed; that is, the positive Bt gene effect is counteracted by a negative germplasm effect. This underlines the finding that the benefits of GM can be fully realized only when the technology is inserted into a number of locally adapted varieties.

Thirtle et al. (2003) used a stochastic frontier approach with data from farmers in South Africa to show that Bt adoption helps to increase the technical efficiency of cotton production in the small-farm sector. Kambhampati et al. (2006) did a similar analysis for India. Many of these econometric analyses used instrumental variable approaches to avoid or reduce selectivity issues and problems of endogeneity. One study by Crost et al. (2007) also used panel data techniques for the estimation of Bt productivity effects.

3.2.3. Gross margin effects. The gross margin effects of Bt technologies are also shown in **Table 1**. In all countries noted, Bt-adopting farmers benefit; that is, the economic advantages associated with insecticide savings and higher effective yields more than outweigh the technology fee charged on GM seeds. The absolute gains differ remarkably among countries and crops. On average, the gross margin gains are higher for Bt cotton than for Bt maize, and they are also higher in developing as opposed to developed countries. In addition to agroecological and socioeconomic differences, the GM seed costs are often lower in developing countries, owing to weaker IPRs, seed reproduction by farmers, subsidies, or other types of government price interventions (Basu & Qaim 2007, Sadashivappa & Qaim 2009).

Agricultural policies are also partly responsible for the different gross margin effects. For instance, in the United States, China, and Mexico, the cotton sector is subsidized, which encourages intensive production schemes and high overall yields. The situation is similar for maize in Spain. By contrast, Argentinean farmers are not subsidized; instead, they face world-market prices. Especially for cotton, world-market prices have been declining over the past 10 years, thus eroding the economic benefits resulting from technological yield gains. Furthermore, within countries, farmer conditions are heterogeneous so that the effects are variable (Qaim et al. 2006, Pemsl & Waibel 2007).

3.3. Poverty and Distribution Effects

Seventy-five percent of all poor people in the world are smallholder farmers or rural laborers. Therefore, GM crops may also have important implications for poverty and income distribution in developing countries. If only rich farmers were to benefit, inequality

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would increase. Yet, if resource-poor farmers could access GM crops suitable for their situations, the poverty and equity effects may be positive. Apart from technological characteristics, this also depends on the institutional setting at national and local levels (Qaim et al. 2000, Evenson et al. 2002). For instance, strong IPRs and high seed prices as well as information, credit, and infrastructure constraints can hinder poor farmers' proper access to GM seeds, even if the underlying technology is suitable for smallholder agriculture (e.g., Qaim & de Janvry 2003, Thirtle et al. 2003, Qaim 2005, Edmeades & Smale 2006).

So far, HT crops have not been widely adopted in the small-farm sector. Smallholders often weed manually, so that HT crops are inappropriate, unless labor shortages or weeds that are difficult to control justify conversion to chemical practices. The situation is very different for Bt crops. Especially in China, India, and South Africa, Bt cotton is often grown by farms with less than 3 ha of land (Huang et al. 2002a,b; Qaim et al. 2008). In South Africa, many smallholders grow Bt white maize as their staple food (Gouse et al. 2006). Several studies show that Bt technology advantages for small-scale farmers are of a similar magnitude as those of larger-scale producers. In some cases, the advantages can be even greater (Pray et al. 2001, Morse et al. 2004, Qaim et al. 2008).[3]

However, few studies exist that have analyzed wider socioeconomic outcomes, including effects on rural employment and household incomes. This dearth of broader microlevel research may be the reason for the ongoing controversy surrounding the poverty and rural development implications of GM crops. Subramanian & Qaim (2009a,b) provide the first comprehensive work in this direction. Building on a village social accounting matrix and multiplier model, they examined direct and indirect effects of Bt cotton adoption in India. Their results show that the technology is employment generating, especially for hired female agricultural laborers, which is due to significantly higher yields in need of harvesting. The technology also generates employment in other sectors linked to cotton production, e.g., trade and services.

Simulated impacts on household incomes are shown in **Figure 3**. Each additional hectare of Bt cotton produces 82% higher aggregate incomes than are obtained from conventional cotton, implying a remarkable gain in overall economic welfare through technology adoption in India. For landless households, the positive income effects are relatively small. More female employment for cotton harvesting is counteracted by less male employment for spraying operations. However, all types of farm households—including those below the poverty line—benefit considerably more from Bt than from conventional cotton. These findings demonstrate that GM crops can contribute significantly to poverty reduction and rural development, when they are suited to the small-farm sector and embedded in a conducive institutional environment.

3.4. Environmental and Health Effects

In addition to the economic and social impacts of GM crops, there are also environmental and health implications. In the public debate, potential environmental risks, such as undesirable gene flow or impacts on nontarget organisms, are often in the fore. Food safety concerns are also raised. Shelton et al. (2009), Weaver & Morris (2005), and

[3]Especially for India, biotech critics still report that Bt cotton ruins smallholder farmers. However, such reports do not build on representative data (Qaim et al. 2006, 2008). Gruère et al. (2008) showed that the occasional claim of a link between Bt cotton adoption and farmer suicides cannot be substantiated.

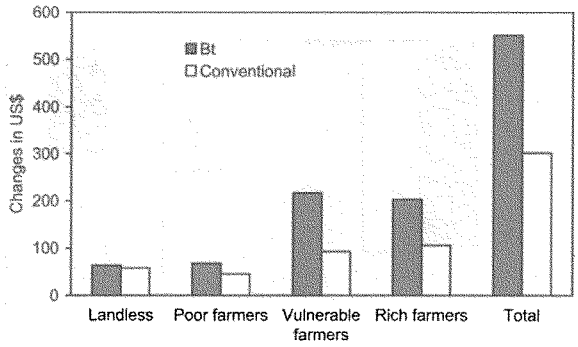


Figure 3

Household income effects of Bt cotton compared with conventional cotton in India. The results are based on simulations with a social accounting matrix and multiplier model for a typical cotton-growing village in the Indian state of Maharashtra. Two simulations were run, both considering an expansion in the village cotton area by 1 ha. The first scenario assumes that the additional hectare is cultivated with Bt cotton, whereas the second assumes that it is cultivated with conventional cotton. Accordingly, differences between the two scenarios can be interpreted as net impacts of Bt technology adoption. Adapted from Subramanian & Qaim (2009a).

Bradford et al. (2005) have reviewed such risks, concluding that most are not specific to the technique of genetic modification but would be present for any conventionally produced crops with the same heritable traits. Although potential risks need to be further analyzed and managed, GM crops can also induce substantial environmental and health benefits.

3.4.1. Environmental benefits. Adoption of HT crops does not lead to reductions in herbicide quantities in most cases, but selective herbicides, which are often relatively toxic to the environment, are substituted by much less toxic broad-spectrum herbicides. Moreover, tillage operations are cut and no-till practices expanded, helping to reduce soil erosion, fuel use, and greenhouse gas emissions (Qaim & Traxler 2005, Brookes & Barfoot 2008).

For Bt crops, the main environmental benefits are related to reductions in chemical insecticide applications. Reductions in pesticide use have been particularly significant in cotton, the most pesticide-consuming crop worldwide. Brookes & Barfoot (2008) estimated that between 1996 and 2006 Bt cotton was responsible for global savings of 128 million kg of pesticide active ingredients, reducing the environmental impact of total cotton pesticides by 25%. **Figure 4** shows that Bt adoption leads to overproportional reductions in the most toxic insecticides.

In the first years of Bt crop deployment, it was predicted that insect populations would soon develop Bt resistance, which would undermine the technology's effectiveness and lead to declining insecticide reductions over time. However, until now, Bt resistance has not been observed under field conditions, which may be due to successful resistance management strategies, such as the planting of non-Bt refuges (Hurley et al. 2001, Bates et al. 2005). In countries where no such strategies are implemented, Bt resistance has also not been reported. However, other factors can lead to changes in Bt effects over time.

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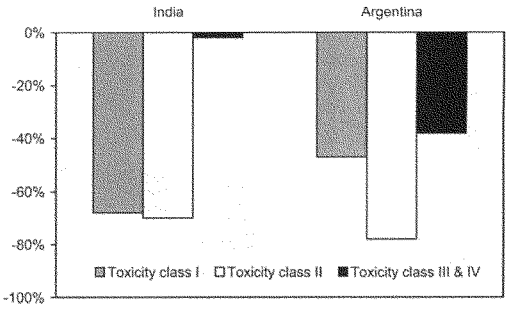


Figure 4

Insecticide reductions through Bt cotton by toxicity class. Results are based on within-farm comparisons obtained from surveys in different cotton-growing regions of India and Argentina. Following the international classification of pesticides, toxicity class I comprises the most toxic products, whereas toxicity class IV comprises the least toxic products. Based on data from Qaim & Zilberman (2003), Qaim et al. (2006), and Qaim & de Janvry (2005).

In China, for instance, insecticide applications increased again after several years of Bt cotton use, in spite of the absence of Bt resistance. Wang et al. (2006) attributed this to secondary pests, which may have become more important through the Bt-induced reduction in broad-spectrum insecticides. Their analysis, however, was based on only one year of observations with increased insecticide applications, making conclusive statements premature (Hu et al. 2006). Using data collected over a period of five years, Sadashivappa & Qaim (2009) did not find any evidence of secondary-pest outbreaks in India.

GM crops may also help preserve agrobiodiversity. Conventional breeding leads to new crop varieties. If a particular new variety produces a large productivity gain, it may spread widely, potentially replacing a large number of older varieties and landraces. This occurred to some extent during the Green Revolution in Asia (Cooper et al. 2005). Developing additional conventional varieties with similar characteristics can be a long and costly process. In contrast, the development of GM traits through genetic engineering can be backcrossed at moderate costs into numerous varieties.[4] Therefore, instead of replacing local varieties, GM versions of these varieties can be made available. Indeed, in most countries where GM technologies have been commercialized, a large number of varieties carrying specific GM traits can be observed (e.g., Qaim 2005, Trigo & Cap 2006, Qaim et al. 2008). More than a technical question, the impact of GM technologies on varietal diversity depends on the design of IPR and biosafety policies, breeding capacities, and other institutional conditions (Zilberman et al. 2007).

3.4.2. Health benefits. GM crops, especially Bt crops, are also associated with health benefits. Direct health advantages for farmers are a result of less insecticide exposure

[4]This is also one reason why genetic engineering is a complementary tool and not a substitute for conventional breeding. GM traits will always have to be incorporated into locally adjusted germplasm.

during spraying operations. Often, the health hazards for farmers applying pesticides are greater in developing as opposed to developed countries because environmental and health regulations are more lax, most pesticides are applied manually, and farmers are less educated and less informed about negative side effects. Pray et al. (2001) and Huang et al. (2003) showed that the frequency of pesticide poisonings was significantly lower among Bt cotton adopters than among nonadopters in China. Hossain et al. (2004) used econometric models to establish that this observation is causally related to Bt technology. Bennett et al. (2003) made the same observation for Bt cotton in South Africa, and there is first evidence that similar effects can also be expected for other Bt crops in smallholder agriculture, such as Bt rice in China (Huang et al. 2005, 2008). Using econometric estimates and a cost-of-illness approach, Krishna & Qaim (2008b) projected that Bt eggplant in India may produce farmer health benefits worth approximately $4 million per year.

For consumers, Bt crops can yield health benefits through lower pesticide residues in food and water. Furthermore, in a variety of field studies, Bt maize was shown to contain significantly lower levels of certain mycotoxins, which can cause cancer and other diseases in humans (Wu 2006). Especially in maize, insect damage contributes significantly to mycotoxin contamination. In the United States and other developed countries, maize is carefully inspected, so lower mycotoxin levels may be most responsible for reducing the costs of testing and grading. But in many developing countries, strict mycotoxin inspections are uncommon. In such situations, Bt technology could contribute to lowering the total health burden (Wu 2006, Qaim et al. 2008).

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4. MACROLEVEL IMPACTS OF FIRST-GENERATION GM CROPS

Numerous studies using macrolevel economic surplus models have analyzed the broader welfare effects of GM crops. When the market of only one single crop is considered, partial equilibrium models are used, whereas general equilibrium models are employed when indirect effects and spillovers to other markets and sectors are also of interest.

4.1. Partial Equilibrium Approaches

Whenever new crop technologies are adopted on a large scale, the productivity increase will cause the crop's supply curve to shift downward, leading to a change in producer and consumer surplus (Alston et al. 1995). Because most GM technologies currently available have been commercialized by the private sector, technology rents accrued by innovating companies need to be considered (Moschini & Lapan 1997).

Price et al. (2003) estimated that in the late 1990s Bt cotton generated a total annual economic surplus gain of approximately $164 million in the United States, of which 37% was captured by farmers, 18% by consumers, and 45% by the innovating companies. Falck-Zepeda et al. (2000b) also reported similar results. Because Bt cotton adoption in the United States has increased since then, absolute surplus gains are higher today, but relative surplus distribution remains approximately the same (Fernandez-Cornejo & Caswell 2006).

For Bt cotton in China, Pray et al. (2001) estimated economic surplus gains of approximately $140 million in 1999, with only 1.5% going to the innovating companies and the rest captured by farmers. IPR protection in China is weak, and use of farm-saved Bt cottonseeds is widespread. Under these conditions, it is difficult for companies to capture innovation rents. Cotton consumers did not benefit in 1999 because the government

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controlled output markets, thus preventing a price decrease. Recently, markets have been liberalized, so Chinese consumers now benefit from Bt cotton technology. In India, Bt cotton surplus gains were projected at $315 million for 2005 (Qaim 2003). Because cotton prices there are not fully liberalized, consumer benefits were not considered. Farmers capture two thirds of the overall surplus gains; the rest accrues to biotech and seed companies. Bt cotton in India is commercialized in hybrids, so use of farm-saved seeds is low. Thus, the private sector innovation rent is higher than in China.

For Bt maize in the United States, Wu (2002) estimated a total surplus gain of $334 million in 2001. Approximately half of the gain accrued to producers, followed by industry profits (31%). The consumer share was relatively small. For Bt maize in Spain, Demont & Tollens (2004) calculated welfare gains of approximately $2 million in 2003, of which 60% went to farmers and 40% to seed companies. The relatively low absolute gain is due to the fact that Bt maize in 2003 covered only an area of approximately 25,000 ha. Similar effects were shown during the early years of Bt maize adoption in the Philippines (Yorobe & Quicoy 2006).

A number of studies have examined the partial equilibrium effects of HT soybeans (e.g., Moschini et al. 2000, Falck-Zepeda et al. 2000a, Qaim & Traxler 2005). Most of these studies use multiregion models. Worldwide welfare gains of HT soybeans were on the order of US$1 billion in the late 1990s. Gains have grown since then as a result of increased adoption. At the global level, downstream sectors and consumers are the main beneficiaries, capturing more than 50% of surplus gains. The effects vary strongly by country, however. Within the United States, farmers capture approximately 20% of the national welfare gains versus almost 60% accruing to Monsanto as the innovating company. By contrast, in Argentina, the farmer surplus share is 90%. These differences are largely due to different levels of IPR protection (Qaim & Traxler 2005).

In addition to such ex post studies, ex ante studies for GM crops have also been carried out in different countries. Examples include analyses for Bt maize and different HT crops in the EU (Demont et al. 2004, 2008), HT rice in Uruguay (Hareau et al. 2006), Bt eggplant in India (Krishna & Qaim 2008b), drought-tolerant rice in India and Bangladesh (Ramasamy et al. 2007), and virus- and insect-resistant sweet potato in Kenya (Qaim 2001). These ex ante studies confirm that GM crops can bring about sizeable welfare gains, with distributional effects dependent on IPRs and other institutional conditions.

4.2. General Equilibrium Approaches

Many of the available general equilibrium studies use the multiregion computable general equilibrium (CGE) model and associated database of the Global Trade Analysis Project (Hertel 1997). This model captures the vertical and horizontal linkages between markets within regions and between regions via bilateral trade flows. The results of several global impact studies are summarized in **Table 2**.

Bt cotton adoption entails global welfare gains in the range of $0.7–1.8 billion per year. The differences across studies partly reflect the use of different versions of the basic model. More importantly, however, the assumed technology adoption rates in different regions matter. Because Bt adoption continues to increase, the aggregate welfare gains are increasing too. Most CGE studies for Bt cotton to date found the biggest regional welfare effects occurred in China (e.g., Huang et al. 2004, Frisvold & Reeves 2007), but India, where the technology was commercialized later, has been catching up rapidly. Anderson et al. (2008)

Table 2 Projected global welfare gains from GM crops (CGE model results)[a]

Reference	Crop	Year of study	Annual welfare gain (US$)
Frisvold & Reeves (2007)	Bt cotton	2005	1.4 billion
Elbehri & MacDonald (2004)	Bt cotton	2001	1.8 billion
Anderson & Yao (2003)	Bt cotton	2005	1.4 billion
Anderson et al. (2008)	Bt cotton	2001	0.7 billion
Nielsen & Anderson (2001)	GM oilseeds and maize	—	9.9 million
Anderson & Yao (2003)	GM soybean and maize	—	7.0 billion
Hareau et al. (2005)	Bt rice	—	2.2 billion
Hareau et al. (2005)	Drought-tolerant rice	—	2.5 billion
Hareau et al. (2005)	HT rice	—	2.1 billion
Anderson & Yao (2003)	GM rice	—	2.0 billion

[a]Abbreviations: CGE, computable general equilibrium; GM, genetically modified; HT, herbicide tolerant.

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estimate that widespread adoption of Bt cotton in India and other countries of South Asia will result in additional regional welfare gains on the order of $1 billion per year.

Larger international markets result in bigger effects for GM oilseeds and maize. With widespread international adoption of HT and insect resistance in these crops, annual welfare gains could be approximately $10 billion (Nielsen & Anderson 2001). A ban on production and imports by the EU, however, could reduce these global gains by two thirds, because of foregone benefits for domestic consumers and the far-reaching influence of EU policies on international trade flows and production decisions in exporting regions (Tothova & Oehmke 2005).

For GM rice, large global welfare gains are projected as well. For other rice technologies, such as Bt, HT, and drought tolerance, and assuming moderate adoption levels in rice-producing regions, Hareau et al. (2005) estimated global welfare gains of $2.1–2.5 billion per year, with India and China gaining the most. Huang et al. (2004) projected that the welfare gains in China alone could reach over $4 billion when different first-generation GM rice technologies are widely adopted. The studies available to date provide lower bound estimates of the global welfare effects of GM crops, because positive environmental and health externalities have not been properly quantified.

5. POTENTIAL IMPACTS OF SECOND-GENERATION GM CROPS

First-generation GM crops involve direct productivity and income effects, which can be evaluated at the micro level and then integrated into macrolevel modeling approaches. Second-generation crops, which involve enhanced quality attributes, must be evaluated differently. Quality improvements generally lead to a marginal utility increase and a higher willingness to pay (WTP) among consumers. In a market model, this can be represented as an upward shift in the crop's demand function. There are no ex post impact studies available for second-generation GM crops, because such crops have not been widely adopted. However, several authors have carried out conceptual analyses and ex ante

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simulations of the welfare effects under different conditions in developed countries (e.g., Jefferson-Moore & Traxler 2005, Giannakas & Yiannaka 2008).

In developing countries, the situation is different, especially when looking at technologies that are targeted to the poor, such as biofortified GM crops. Widespread production and consumption of biofortified staple crops could reduce micronutrient deficiencies, improve health outcomes, and provide economic benefits (Bouis 2007). Yet, it is uncertain if they would command higher market prices, because the poor are often not aware of their micronutrient deficiencies and may not be willing or able to pay a quality premium. Therefore, biofortified crops in developing countries may not lead to an upward shift in demand, so social welfare effects must be evaluated differently (Qaim et al. 2007).

Dawe et al. (2002) looked at the potential nutritional effects of Golden Rice by analyzing likely improvements in vitamin A intakes in the Philippines. This approach implicitly builds on a measure of program success that has been used for other micronutrient interventions, namely the achieved reduction in the number of people with micronutrient intakes below a defined threshold. However, since micronutrient intake is not an end in itself but only a means to ensure healthy body functions, it is more appropriate to go further and quantify health outcomes directly. Zimmermann & Qaim (2004) and Stein et al. (2006) suggested an alternative approach in their analyses of the potential health benefits of Golden Rice. They defined the benefit of the technology as the difference in health costs related to vitamin A deficiency with and without Golden Rice.

In their ex ante analysis, Stein et al. (2008) used representative household data from India to show that Golden Rice could reduce the health costs of vitamin A deficiency by up to 60%. They also calculated a high cost-effectiveness of Golden Rice, which compares favorably with other nutrition and health interventions, and a high social rate of return, which compares favorably with other agricultural R&D investments (Qaim et al. 2007). Anderson et al. (2005) used a macro CGE model to simulate the benefits of Golden Rice at the global level. Modeling consumer health effects among the poor as an increase in the productivity of unskilled laborers, they estimated worldwide welfare gains of over $15 billion per year, with most of the benefits accruing in Asia. In China, for instance, Golden Rice was projected to entail a 2% growth in national income (Anderson et al. 2005).

Significant economic and health benefits can also be expected for other biofortified crops, such as iron- and zinc-dense staple foods or crops containing higher amounts of essential amino acids (Qaim et al. 2007). The potentially high cost-effectiveness of biofortification in developing countries is due to the fact that the approach is self-targeting to the poor, with biofortified seeds spreading through existing formal and informal distribution channels. However, possible issues of consumer acceptance must be considered. Especially when no price premium is paid in the output market, suitable strategies to convince farmers to adopt such crops are needed. A combination of quality traits with interesting agronomic traits may be a practicable avenue.

6. CONSUMER ACCEPTANCE OF GM CROPS

In spite of the great potential of GM crops and the benefits that have already materialized, public attitudes toward the technology are often negative, and consumer acceptance remains an issue.[5] Consumer perceptions are often dominated by health, environmental,

[5]This is in contrast to pharmaceutical applications of GM technologies, which are widely accepted by the public.

social, and ethical concerns, which are not always based on the best information but which have emerged as important driving forces of biotechnology policies (Miller & Conko 2004, Paarlberg 2008). One reason for the partial acceptance may be that most GM crops now available involve agronomic traits with limited direct benefits to consumers. Consumer acceptance may increase when second-generation, quality-enhanced GM foods or crops with combined agronomic and quality traits are introduced.

Aspects of GM crop acceptance have been widely analyzed in the literature; most studies determine consumers' WTP for GM-free foods or the willingness to accept a discount for GM foods. These findings help us understand the values consumers attach to the GM attribute especially in the absence of observable market data. There are two approaches used for estimating WTP. The first approach involves choice modeling or contingent valuation surveys to obtain stated-preference data from consumers. Most of the available studies for GM crops build on this approach, both in developed (e.g., Lusk 2003, McCluskey et al. 2003, Moon & Balasubramanian 2004) and developing countries (e.g., Kimenju & De Groote 2008, Krishna & Qaim 2008a). The advantage of stated-preference surveys is that representative data can be obtained. The disadvantage, however, is the potential hypothetical bias, as consumers state their preferences without any direct financial implications. The second approach avoids this bias through experimental auctions, although samples are usually smaller and not representative of the total population. The experiments are often designed such that participants bid with real money or are presented with opportunities to exchange a given GM product for a corresponding GM-free product or vice versa. Such experimental auctions have been used for analyzing consumer acceptance in the United States and the EU (e.g., Huffman et al. 2003, Lusk et al. 2006).

Lusk et al. (2005) provide a meta analysis, regressing the WTP results from individual studies on a set of explanatory variables. Across all studies in the analysis, the weighted mean WTP for GM-free products is a premium of 23% more than that for GM products. However, remarkable differences arise. The WTP is significantly higher in Europe than in the United States, and it is significantly lower for processed than for fresh GM foods. Studies using experimental auctions result in a lower WTP for GM-free foods on average. Individual analyses also show a significant influence of consumer characteristics such as age, education, income, or gender, but the direction of the influence is not uniform.

A difference in WTP for GM and GM-free products indicates that many consumers do not consider these options as perfect substitutes. In that case, introducing GM technology would be associated with a negative externality, which would need to be accounted for in welfare economics studies (Giannakas & Fulton 2002, Lapan & Moschini 2004). However, past experience shows that both stated-preference and experimental data do not always correctly predict actual consumer behavior. Moreover, consumer responses are strongly dependent on the type of information available at a certain point (Huffman et al. 2003), so GM acceptance may potentially change rapidly. The public media play an important role. Especially in Europe, media reports about GM crops have been predominantly negative.

In general, available studies suggest that second-generation GM foods will be more acceptable to consumers than first-generation products (Lusk et al. 2005). This supports the hypothesis that GM acceptance levels will rise when quality-enhanced crops with more direct consumer benefits become available. There are also indications that consumers in developing countries have more positive attitudes toward GM food than their counterparts in developed countries (e.g., Kimenju & De Groote 2008, Krishna & Qaim 2008a).

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One possible explanation is that they are generally poorer and sometimes food insecure; thus they may be more open to productivity-increasing technologies.

7. ECONOMICS OF GM CROP REGULATION

Because GM crops are associated with several potential market failures, the technology is heavily regulated. For instance, GM crops may be associated with environmental and health externalities, so biosafety and food safety regulations have been put in place. For consumers, the GM characteristic of food products is a credence attribute, indicating that labeling regulations can help to reduce transaction costs and problems of asymmetric information. The development of GM technologies leads to public goods that can easily be reproduced, so IPR protection is needed as an incentive for private sector R&D investments. However, because every regulation is associated with trade-offs, the optimal level should be determined on the basis of solid economics research (Just et al. 2006).

7.1. Biosafety and Food Safety

Governments have an important role in ensuring that novel foods are safe for human consumption and that novel agricultural inputs do not cause major negative impacts on the environment and long-term agricultural production possibilities. Most countries, with the notable exception of the United States, consider GM crops to be novel foods, regardless of the characteristics of their final product. Hence, new laws and institutions to regulate potential biosafety and food safety issues have been established, requiring that GM products be approved before they may be grown in, consumed in, or imported into a country (Herdt 2006). Because approval processes are not internationally harmonized, they have become a major barrier to the spread of GM crops and technologies around the world. For instance, the EU has not yet approved some of the GM maize technologies that are used in the United States and Argentina, which obstructs trade not only in technologies but also in commodity and food markets. In the EU, this is related to public-acceptance problems. In other parts of the world, however, the lack of GM crop approvals is often due to human and financial capital constraints. Smaller developing countries, in particular, have been unable to legislate and operate a biosafety regulatory system to date. This has shut them off from some of the international markets (Pray et al. 2006).

In countries where a biosafety system is in place, most of regulators' efforts are put into preventing the commercialization of products that may harm people or the environment (i.e., type I errors). Often, regulators are extremely cautious, requiring many regulatory trials over a long period of time. However, lengthy biosafety and food safety testing procedures come at a cost. Kalaitzandonakes et al. (2007) estimated the private compliance costs for regulatory approval of a new Bt or HT maize technology in one country at $6–15 million. Commercializing the same technology in other countries will entail additional costs. Beyond these direct regulatory costs, there are indirect costs in terms of foregone benefits (preventing the use of safe products is referred to as type II errors). Pray et al. (2005) estimated that a two-year delay in the approval of Bt cotton in India led to aggregated losses to farmers of more than $100 million.

Such high regulatory costs slow down overall innovation rates. They also impede the commercialization of GM technologies in minor crops and small countries, as markets in

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such situations are not large enough to justify the fixed-cost investments. Expensive regulations are also difficult to handle by small firms and public sector organizations, thereby contributing to the further concentration of the agricultural biotech industry. Were such lengthy and complex procedures necessary to regulate high-risk products, then the costs involved would be justified. But this does not seem to be the case. Because the use of genetic engineering does not entail unique risks, it is illogical to subject GM crops to a much higher degree of scrutiny than conventionally bred crops (Bradford et al. 2005). The regulatory complexity observed today appears to be the outcome of the politicized public debate and the lobbying success of antibiotech interest groups (Miller & Conko 2004).

Some reform of the GM regulatory framework will be necessary, and economists have an important role in this respect in terms of quantifying costs and benefits. Lichtenberg & Zilberman (1988) suggested a safety rule approach for more efficient pesticide legislation under uncertainty. The same approach could also be useful in the context of GM crops. It combines a probabilistic risk assessment model with a safety rule decision mechanisms that is equivalent to the use of significance levels for statistical decision making (Sexton et al. 2007). The safety rule approach can be employed for cost-benefit or risk-benefit analyses. Hence, transparent criteria and maximization techniques are used to bring science and objectivity to decision-making processes that are often influenced by political economy considerations and a precautionary approach.

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7.2. Labeling and Coexistence

Several countries have introduced or considered introducing a food-labeling system. In general, mandatory or voluntary labeling is possible. Mandatory labeling is often used to warn consumers of specific health risks (e.g., cigarettes), whereas voluntary labeling is more common to differentiate products with desirable characteristics for marketing purposes (e.g., organic). Both systems can convey the same information to consumers. Given that only GM products that are considered to be safe are approved for market release, no warning of risks is required on labels. Therefore, the issue is mainly one of heterogeneous consumer preferences, which—from an economics perspective—would be best addressed through voluntary labeling of GM-free products (Golan et al. 2001). The EU, however, has established a mandatory system, which is more costly and can reinforce the notion that GM products are inherently unsafe. The motivation underlying the EU approach is that consumers have a right to know, which is different from the need to know approach in the context of risk communication. Moschini (2008) argued that the right to know approach is too open ended and potentially unbounded, because it can be invoked for virtually anything.

Labeling involves market segregation and a system of identity preservation, which can be quite costly. The cost is negatively correlated with the threshold levels allowed for the adventitious presence of GM material. Again, these thresholds are not related to risks but are a political decision; very low thresholds can lead to prohibitive segregation costs. Giannakas & Fulton (2002) and Lence & Hayes (2005) showed that labeling in general and segregation costs in particular can influence the welfare effects of GM crops significantly. Dissimilar approaches across countries can also lead to serious problems in international trade.

Labeling and segregation are also related to coexistence. The EU, in particular, has established rules to ensure the coexistence of GM crops with conventional and GM

farming, which involve a number of technical and legal specifications, from minimum distance requirements for cultivation to liability and insurance measures (Beckmann et al. 2006). The high degrees of complexity, uncertainty, and direct costs associated with these coexistence rules represent clear disincentives for EU farmers to adopt GM crops (Demont & Devos 2008, Breustedt et al. 2008).

7.3. Intellectual Property Rights and Public-Private Partnerships

In the United States and most other developed countries, living organisms and parts thereof have been patentable since the 1980s. This has spurred a tremendous amount of private sector biotechnology research. Nowadays, more than 75% of all patents in agricultural biotechnology are held by the private sector, mostly by a few large multinational corporations (Graff et al. 2003). Although strong patents and other forms of IPRs provide an incentive for private sector R&D, they are associated with higher prices and the usual static welfare losses in monopoly situations. As noted above, the degree of IPR protection in a country has an influence on GM crop adoption and benefit distribution. When GM seed prices are too high, resource-poor farmers face access problems (Qaim & de Janvry 2003). Therefore, the optimal level of IPR protection and enforcement is situation specific (Giannakas 2002).

The proliferation of IPRs on genes, processes, and technologies has led to access and freedom-to-operate problems within the biotechnology industry. Because the development of a single GM crop may require the use of dozens of patented intermediate technologies, licenses have to be negotiated with multiple parties, involving high transaction costs (Santaniello et al. 2000). In that sense, the freedom-to-operate problem may contribute to further industry concentration. Public sector research organizations, in particular, are at a disadvantage because they often have relatively little to offer in return for licenses from private companies. Even the largest public sector patent holders, such as the University of California and the United States Department of Agriculture, own less than 2% of total agricultural biotechnology patents versus the more than 10% owned by individual multinational companies such as Monsanto and DuPont (Graff et al. 2003).

However, public sector organizations combined hold 24% of the patents, and in some areas they could develop GM crops without relying on patents from the private sector. Graff & Zilberman (2001) suggested an IPR clearinghouse mechanism to reduce transaction costs for such public sector collaborations and joint ventures. A working example is the Public Intellectual Property Resource for Agriculture (PIPRA), bringing together intellectual property from more than 40 universities and public agencies and helping make their technologies available to innovators around the world (http://www.pipra.org).

Such public sector initiatives are important, as certain research and technology areas will not be addressed by private companies because of the limited size of the potential markets or other constraints. Examples include technologies designed especially for poor farmers and consumers in developing countries (Qaim et al. 2000, Lipton 2001). In such areas, more public research is needed. Moreover, more public-private partnerships should be sought to harness the comparative strengths of both sectors (Rausser et al. 2000, Byerlee & Fischer 2002). Usually, universities are better suited to carry out basic research, whereas private companies have advantages in more applied research and development

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(Rajagopal et al. 2009). There are numerous examples of public-private research cooperation in agricultural biotechnology, but none of these projects has yet led to a commercialized GM crop. Ex ante studies show that well-designed partnerships can be advantageous for all parties involved (Krishna & Qaim 2007, 2008b). Nonetheless, more research is needed to develop best practices for the transfer of technologies and know-how as well as the development and commercialization of GM crops.

8. CONCLUSION

GM crops have been used commercially for more than 10 years. To date, most of the GM crops employed have been HT and insect resistant. Available impact studies show that these crops are beneficial to farmers and consumers and produce large aggregate welfare gains. Moreover, GM crops bring about environmental and health benefits. GM crops may also be well suited for small-scale farmers, because such seed technologies are scale neutral. The empirical evidence shows that Bt crops in particular can have significant income-increasing and poverty-reducing effects. Farmers in developing countries sometimes benefit more than farmers in developed countries, which is partly a result of weaker IPR protection and, thus, lower seed prices. Yet, income distribution effects also depend on the wider institutional setting, including farmers' access to suitable seed varieties, credit, information, and other input and output markets. More public and institutional support will be needed to realize the benefits for the poor on a larger scale.

GM technologies currently in the research pipeline include crops that are tolerant to abiotic stresses and crops that contain higher amounts of nutrients than traditional crops. The benefits of such applications could be much greater than the ones already observed. Against the background of a dwindling natural resource base and growing demand for agricultural products, GM crops could contribute significantly to food security and sustainable development at the global level. New technologies are crucial for the necessary production increases.

In spite of these potentials, public opinion regarding GM crops remains divided, especially in Europe. Concerns about new risks and lobbying efforts of antibiotech groups have led to complex and costly biosafety, food safety, and labeling regulations, which slow down innovation rates and lead to a bias against small countries, minor crops, small firms, and public research organizations. Overregulation has become a real threat for the further development and use of GM crops. The costs of regulation in terms of foregone benefits may be large, especially for developing countries. This is not to say that zero regulation would be desirable, but the trade-offs associated with regulation should be considered. In the public arena, the risks of GM crops seem to be overrated, while the benefits are underrated.

Economics research has an important role to play in finding ways to maximize the net social benefits. More work is needed to quantify possible indirect effects of GM crops, including socioeconomic outcomes as well as environmental and health impacts. Furthermore, economists need to contribute to the design of efficient regulations and innovation systems in light of changing framework conditions. Although the gradual move from public to private crop improvement research is a positive sign of better-functioning markets, certain institutional factors seem to contribute to increasing industry concentration. This could lead to adverse outcomes in terms of technology development and access. Such issues need further analysis.

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SUMMARY POINTS

1. GM crops have been used commercially for more than 10 years in developed and developing countries. So far, herbicide-tolerant and insect-resistant Bt crops have been the primary ones employed.
2. Impact studies show that these crops are beneficial to farmers and consumers and produce large aggregate welfare gains. In many cases, farmers in developing countries benefit more than farmers in developed countries.
3. Moreover, GM crops bring about environmental and health benefits. Bt crops in particular allow significant reductions in chemical pesticides.
4. Bt crops can also be suitable for small-scale farmers. Evidence from India and other developing countries shows that they contribute to higher household incomes and poverty reduction, when embedded in a conducive institutional environment.
5. Future GM crop applications, involving tolerance to abiotic stress and higher nutrient contents, may lead to much larger benefits.
6. Against the background of a dwindling natural resource base and growing demand for agricultural products, GM crops can contribute significantly to food security and sustainable development at the global level.
7. In spite of these potentials, public opinion still regards the use of GM crops as controversial. Concerns about new risks have led to complex and costly biosafety, food safety, and labeling regulations.

FUTURE ISSUES

1. Overregulation has become a real threat for the further development and use of GM crops. The costs in terms of foregone benefits may be large, especially for developing countries.
2. Economics research has an important role to play in finding ways to maximize the net social benefits. More work is needed to quantify possible indirect effects of GM crops, including socioeconomic outcomes as well as environmental and health impacts.
3. Furthermore, economists need to contribute to designing efficient regulatory mechanisms and innovation systems.
4. Although the gradual move from public to private crop-improvement research is a positive sign of better-functioning markets, certain institutional factors seem to contribute to increasing industry concentration.
5. Especially with a view to small-scale farmers, more public research and institutional support are needed to complement private sector efforts.

DISCLOSURE STATEMENT

The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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Evolved resistance to glyphosate in rigid ryegrass (*Lolium rigidum*) in Australia

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Following 15 yr of successful use, glyphosate failed to control a population of the widespread grass weed rigid ryegrass in Australia. This population proved to be resistant to glyphosate in pot dose-response experiments conducted outdoors, exhibiting 7- to 11-fold resistance when compared to a susceptible population. Some cross-resistance to diclofop-methyl (about 2.5-fold) was also observed. Similar levels of control of the resistant and susceptible populations were obtained following application of amitrole, chlorsulfuron, fluazifop-P-butyl, paraquat, sethoxydim, simazine, or tralkoxydim. The presence of glyphosate resistance in a major weed species indicates a need for changes in glyphosate use patterns.

Nomenclature Amitrole; chlorsulfuron; diclofop-methyl; fluazifop-P-butyl; glyphosate; paraquat; sethoxydim; simazine; tralkoxydim; rigid ryegrass, *Lolium rigidum* Gaud. LOLRI.

Keywords Herbicide resistance, glyphosate resistance, LOLRI.

Glyphosate is the world's most widely used herbicide, accounting for 11% of worldwide herbicide sales (Powles et al. 1997). It is a nonselective herbicide with no soil activity (Grossbard and Atkinson 1985). Therefore, it is an ideal herbicide for use preplant, in fallow fields, and for spot or directed use to control an extensive range of annual and perennial weeds. Glyphosate has been widely used for all of these purposes for more than 20 yr (Bradshaw et al. 1997). Recently, genetically-engineered glyphosate-tolerant crops, notably soybean [*Glycine max* (L.) Merr.] and cotton (*Gossypium hirsutum* L.), have been marketed in North America under the Roundup Ready® label (Padgette et al. 1996; Powles et al. 1997). This development will undoubtably increase glyphosate use.

The intensive use of herbicides in agriculture has led to the appearance of resistant weed populations (Holt et al. 1993; Powles and Holtum 1994). In a few agricultural areas, the development of widespread herbicide resistance in weeds has compromised the use of certain herbicide chemistries (Powles et al. 1997). In some cases, such as the acetolactate-inhibiting sulfonylurea herbicides, resistance has appeared remarkably rapidly (Gill 1995; Saari et al. 1994); however, for other herbicides, resistance has appeared sporadically or not at all. This is so for glyphosate, where, through more than two decades of use, no cases of herbicide resistance from field use have been reported (Bradshaw et al. 1997; Dyer 1994).

Rigid ryegrass is a widely established grass weed of crops in southern Australia that has displayed a propensity to evolve resistance to herbicides (Hall et al. 1994; Preston et al. 1996). Rigid ryegrass is present in large numbers over the 40 million ha that embrace the southern Australian winter cropping and pasture region, and currently, populations of this species display resistance to most of the major herbicide chemistries in use in Australia, except glyphosate (Hall et al. 1994; Powles et al. 1997; Preston et al. 1996). However, glyphosate is now widely used to control rigid ryegrass across this region, and the intense selection pressure thus applied to this particularly resistance-prone species makes glyphosate resistance a likely outcome. A preliminary report (Pratley et al. 1996) has suggested glyphosate resistance can evolve in rigid ryegrass.

Here, we document evolved resistance to glyphosate in a population of rigid ryegrass from an orchard in Australia following two to three annual applications of glyphosate for 15 yr.

Materials and Methods

The putative resistant biotype of rigid ryegrass was originally obtained from an orchard near Orange, New South Wales, Australia. Glyphosate at 720 to 1,440 g ae ha^{-1} had been used two or three times a year for 15 yr to control weeds within rows of trees. Seed from plants growing in the orchard was collected in December 1995. Seedlings from this seed were treated with glyphosate at 450 g ae ha^{-1} on two separate occasions during May 1996 at the three-leaf stage and the three-tiller stage. Survivors of this treatment were crossed among themselves as described by Tardif et al. (1996), and the resulting F_1 seed was used for all further

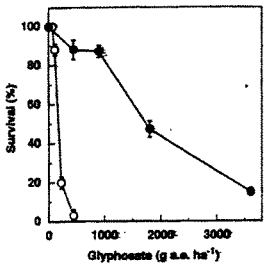


FIGURE 1. Response of the known susceptible (○) and putative resistant (●) populations of rigid ryegrass to varying dose rates of glyphosate isopropylamine. Data are from a single dose-response experiment with four replicates conducted on seedlings growing in pots. Points are mean survival ± SE.

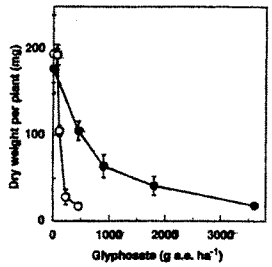


FIGURE 2. Dry weight of the known susceptible (○) and putative resistant (●) populations of rigid ryegrass 21 d after application (DAA) of varying rates of glyphosate isopropylamine. Data are from a single dose-response experiment with four replicates conducted on seedlings growing in pots. Points are mean dry weight per plant ± SE.

experiments. A known susceptible rigid ryegrass population was used as a control in all experiments.

Pot dose-response experiments were conducted outdoors during autumn and winter, the normal growing season for this species in southern Australia. Seed was germinated in a germination cabinet 12 h, 19 C, 30 μmol m^{-2} s^{-1} light period, 12 h, 19 C dark period for 6 d. Germinated seedlings were transplanted to 17-cm-diam pots containing potting soil with 12 seedlings per pot and were grown outdoors. Glyphosate was applied at a range of rates from 0 to 7,200 g ae ha^{-1} to plants at the two- to three-leaf stage of development. Four glyphosate dose-response experiments were conducted. Experiment 1 used glyphosate ammonium[1] applied on April 16, 1997; Experiment 2 used glyphosate ammonium applied on May 5, 1997; Experiment 3 used glyphosate ammonium applied on June 6, 1997; and Experiment 4 used glyphosate trimesium[2] applied on August 22, 1997. Other herbicides used—amitrole, chlorsulfuron, fluazifop-P-butyl, paraquat, sethoxydim, simazine, and tralkoxydim—were applied at the lowest normal use rate to control rigid ryegrass in Australia, except for diclofop-methyl, which was applied at rates ranging from 0 to 1,500 g ai ha^{-1}. These herbicides were applied to plants at the two- to three-leaf stage from May to August 1997. For each herbicide rate, four replicate pots were used. Herbicides were applied with a laboratory moving boom sprayer equipped with T-jet fan nozzles, at a speed of 1 m s^{-1}. Output from the sprayer was calibrated at 139 L ha^{-1} at a pressure of 250 kPa. All herbicides were applied as commercial formulations, with adjuvants as recommended by the herbicide manufacturers.

Plants were returned outdoors after treatment, and the response to herbicides was recorded after 21 d. Plants were recorded as alive if they had strongly tillered since application of the herbicide. Shoots were removed at soil level and dried at 60 C for 72 h to a constant weight. Mortality data were subject to probit analysis using the computer program POLOPC (1987) to determine LD_{50} values. Probit analysis gives equations of the following form:

$$Y = 5 + (a + b \log_e) \qquad [1]$$

where Y is the expected probit, a is the intercept and b the slope of the probit line, and $\log_e$ is the log of the dose rate (Finney 1971). The LD_{50} can be calculated from this equation by solving for a probit of 5.

Results and Discussion

The known susceptible population of rigid ryegrass was readily controlled by glyphosate, with very few survivors at rates of 450 g ae ha^{-1} or higher (Figure 1). In contrast, the putative resistant population was markedly less affected by glyphosate, requiring high rates for substantial mortality. Glyphosate at 450 g ae ha^{-1} dramatically reduced dry weight accumulation of the susceptible population and also clearly damaged the resistant plants (Figure 2); however, most of the latter plants survived. At this rate, dry weight accumulations of the susceptible and resistant populations were 9 and 59% of untreated controls, respectively.

This experiment was repeated three times with the isopropylamine salt formulation of glyphosate and once with the trimesium salt formulation of glyphosate, and in each case, the orchard population displayed resistance. The concentration of herbicide required to kill 50% (LD_{50}) of the susceptible population varied between 59 and 174 g ae ha^{-1}, depending on the season and type of formulation (Table 1). The LD_{50} for the resistant population varied between 600 and 1,800 g ae ha^{-1}. On all occasions, the resistant population proved to be between 7- and 11-fold resistant. Lower rates of glyphosate isopropylamine were required to control both populations in May and June during cooler weather, compared to April. The recommended rate of glyphosate trimesium for control of annual ryegrass is 33% higher than that for glyphosate isopropylamine. Therefore, it is not surprising that LD_{50}'s for glyphosate trimesium were higher than those obtained for glyphosate isopropylamine under similar environmental conditions.

There have been a number of previous reports of tolerance of populations of plant species to glyphosate. Plant breeders have deliberately selected lines of perennial ryegrass (*Lolium perenne* L.) (Johnston and Faulkner 1991), birdsfoot trefoil (*Lotus corniculatus* L.) (Boerboom et al. 1990, 1991), *Festuca longifolia* Thuill., and red fescue (*Festuca rubra* L.) (Johnston et al. 1989) to attain low level glyphosate toler-

TABLE 1. Amount of glyphosate required for 50% mortality of susceptible and resistant populations of rigid ryegrass in four separate experiments of the type shown in Figure 1. Values are LD_{50}, calculated by probit analysis of the full dose response. Values in parenthesis represent the 95% confidence intervals. R/S is the ratio of LD_{50} of the resistant population to that of the susceptible population.

Experiment	Herbicide formulation	Susceptible	Resistant	R/S
		LD_{50} (g ae ha^{-1})		
1	Glyphosate isopropylamine	174 (156, 200)	1,718 (1,463, 2,137)	10
2	Glyphosate isopropylamine	106 (95, 119)	746 (507, 998)	7
3	Glyphosate isopropylamine	59 (24, 82)	623 (471, 764)	11
4	Glyphosate trimesium	154 (135, 174)	1,258 (1,009, 1,525)	8

ance. Several naturally occurring lines of field bindweed (*Convolvulus arvensis* L.) displayed glyphosate tolerance without selection from glyphosate (DeGennaro and Weller 1984; Duncan and Weller 1987; Westwood and Weller 1997). In all of these cases, resistance appeared to be about two- to fivefold compared to normal lines of the same species. In none of the above cases had resistance appeared in weed species as the result of normal commercial use of glyphosate in the field. A preliminary report, based on a single dose-response experiment conducted under glasshouse conditions, suggests that evolved resistance may have occurred in another population of rigid ryegrass from northern Victoria (Pratley et al. 1996). Here, we have established (Figure 1; Table 1) that substantial resistance to glyphosate is present in a glyphosate-selected field population of rigid ryegrass.

Herbicide cross-resistance (resistance to dissimilar herbicides) is common in populations of rigid ryegrass (Hall et al. 1994; Preston et al. 1996). Cross-resistance poses a serious practical problem for weed control, as it can dramatically reduce the alternative herbicide options available. Therefore, the resistant population was examined for resistance to a range of other herbicides applied at the lowest recommended field rate to both resistant and susceptible populations. The resistant population proved to be as sensitive as the susceptible population to all of these herbicides except diclofop-methyl (Table 2). The possibility of resistance to diclofop-methyl was further examined by conducting a full dose-response experiment (Figure 3). This experiment established that a difference in response to diclofop-methyl was evident between the resistant and susceptible populations; however, the glyphosate-resistant population was only about 2.5-fold resistant to diclofop-methyl at the LD_{50}. This result is significant, as the ryegrass population had not previously been exposed to diclofop-methyl.

Considering the highly successful long-term use of glyphosate (Bradshaw et al. 1997), it is remarkable that more examples of resistant plants have not been identified. Several explanations have been put forward to explain this observation, including the inability to generate functional target-site mutations within enolpyruvylshikimate-3-phosphate (EPSP) synthase in plants (Padgette et al. 1991), and the low rates of metabolism of glyphosate in plants (Komoba et al. 1992). This has led some authors to predict that evolved glyphosate resistance in weeds is unlikely (Bradshaw et al. 1997). The present study has demonstrated that evolved resistance to glyphosate has now appeared in rigid ryegrass.

Worldwide, rigid ryegrass is by far the most resistance-prone weed species, with extensive resistance to numerous herbicides (Hall et al. 1994; Powles et al. 1997; Preston et al. 1996). That resistance has now occurred in a glyphosate-selected field population of rigid ryegrass (Figure 1; Table 1) demonstrates that glyphosate resistance can occur following persistent use. Given the importance of glyphosate in world agriculture, its current high use, and impending increased usage with transgenic crops, the evolution of glyphosate resistance is a significant development in world agriculture. It would be prudent to accept that resistance can occur to this highly valuable herbicide and to encourage glyphosate use patterns within integrated strategies that do not impose a strong selection pressure for resistance.

TABLE 2. Response of susceptible and resistant populations of rigid ryegrass to alternative herbicides applied at the lowest recommended rate. Herbicides were applied to seedlings growing in pots at the two- to three-leaf stage. Values are percent survival ±SE of four replicates.

Herbicide and rate (g active ingredient ha^{-1})	Susceptible	Resistant
	Survival (%)	
Amitrole (700)	40 ± 5	45 ± 5
Chlorsulfuron (15)	3 ± 3	0
Diclofop-methyl (375)	27 ± 6	79 ± 1
Fluazifop-P-butyl (53)	0	0
Paraquat (200)	0	0
Sethoxydim (186.8)	0	0
Simazine (1620)	5 ± 3	2 ± 2
Tralkoxydim (200)	0	0

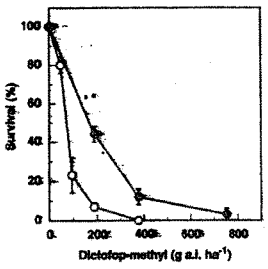


FIGURE 3. Response of the known susceptible (○) and glyphosate resistant (●) populations of rigid ryegrass to varying dose rates of diclofop-methyl. Data are from a single dose response experiment with four replicates conducted on seedlings growing in pots. Points are mean survival ± SE.

Sources of Materials

[1] Glyphosate isopropylamine was Roundup CT® by Monsanto, Australia Ltd., P.O. Box 6051, St. Kilda Road Central, Victoria 8008 Australia.

[2] Glyphosate trimesium (trimethylsulfonium [TMS] salt) was Touchdown® by Crop Care Australasia, Pty. Ltd., P.O. Box 4311, Melbourne, Victoria 3001 Australia.

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Resistance to glyphosate in *Lolium rigidum*. II. Uptake, translocation, and metabolism

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Experiments were conducted to determine potential mechanisms of glyphosate resistance in *Lolium rigidum* from Australia. ^{14}C-Glyphosate uptake, translocation, and metabolism were compared between resistant (R) and sensitive (S) biotypes. The R seed (48118a) represented the F_1 progenies of plants having survived a 1.73-kg ae ha^{-1} (4.8 L ha^{-1}) application of a Roundup® formulation. The S seed was a sensitive biotype of *L. rigidum* from Australia. Plants (one to four tillers, 2 to 4 wk old) were presprayed with a high (1.26 kg ae ha^{-1}) or a low (0.28 kg ae ha^{-1}) dose of formulated glyphosate. The first leaf of the first tiller, which was shielded from the spray, was immediately treated with a ^{14}C-glyphosate solution via manual application to the adaxial surface. Harvest was made 6 days after treatment (DAT), and glyphosate residues in the leaf wash, treated leaf, roots, and shoots were quantified based on radioactivity as percentage of applied dose. The overall radioactivity recoveries were very good (90.2 to 97.3% of applied dose). R and S plants showed comparable uptake at the high (79.2 vs. 78.0%) or the low (64.0 vs. 64.7%) doses of glyphosate. About one-half of the absorbed glyphosate in both R and S (32.9 to 38.3% appl.) was translocated into the plant and distributed almost equally into roots (13.6 to 16.0% appl.) and shoots (18.1 to 22.6% appl.). Autoradiography studies demonstrated no difference in tissue localization of glyphosate between the R and S plants. For metabolism studies, tissues from individual plants were homogenized in water, and extracts were analyzed by anion exchange high-pressure liquid chromatography (HPLC) with radioactivity detection. There was little to no metabolism of glyphosate in extracts from various tissues of either R or S plants. Based on these results, we conclude that neither uptake, translocation, nor metabolism play a major role in glyphosate resistance in *L. rigidum*.

Nomenclature: Glyphosate; *Lolium rigidum*, LOLRI, rigid ryegrass.

Key words: Herbicide resistance, glyphosate resistance, LOLRI.

Herbicide resistance is a frequent topic of review in the literature stemming from an increasing number of cases worldwide (Heap 1997; Holt et al. 1993; Moss and Rubin 1993). An international survey documented over 216 weed species that have evolved resistance to herbicides (Heap 1997). About one-third of these cases involve triazine resistance. Resistance to acetolactate synthase (ALS) inhibitors shows the fastest increase.

Among herbicide-resistant weeds, *Lolium rigidum* is perhaps the most infamous. *Lolium rigidum* is the first example of a weed that demonstrated cross-resistance to multiple herbicide chemistries including aryloxyphenoxyproprionates, cyclohexanediones, sulfonylureas, and dinitroanilines (Powles et al. 1990). Studies have shown that the mechanism of *L. rigidum* resistance is not due to any barrier to herbicide uptake or translocation but to induction of several herbicide degradation enzymes (Preston et al. 1996). Several factors have been attributed to the development of herbicide resistance in *L. rigidum* in Australia, including wide distribution; diverse genetic background; a requirement for cross-pollination facilitating outcrossing; and high selection pressure from repeated use of the same herbicides (Tardif et al. 1997).

Evolvement of weed resistance to glyphosate in the environment has been perceived to be a highly unlikely event (Bradshaw et al. 1997). However, *L. rigidum* resistance to glyphosate has been detected in Australia. The first case of resistance was observed in a field in Echuca, Australia, where glyphosate had been applied repeatedly for presowing control of weeds (Pratley et al. 1996). The second case was reported recently in an orchard in Australia following multiple annual applications of glyphosate for 15 yr (Powles et al. 1998). Pratley et al. (1999) describe bioevaluation of glyphosate resistance in *L. rigidum* from the Echuca site. The present manuscript examines the uptake, translocation, and metabolism of ^{14}C-glyphosate in the resistant *L. rigidum*.

Materials and Methods

R and S seed of *L. rigidum*[1] was provided by Charles Sturt University, Wagga Wagga, Australia. The R seed represented the F1 progenies of plants having survived a 4.8-L ha^{-1} (1.73 kg ae ha^{-1}) application of Roundup (360 g L^{-1}). The S seed was a sensitive biotype of *L. rigidum* from Australia.

Glyphosate, ^{14}C-labeled at the phosphonomethylene (C-3) site,[2] was obtained from New England Nuclear. The specific activity of ^{14}C-glyphosate was 1,457 MBq mmol^{-1} (517,000 dpm μg^{-1}), and it was determined to be 99.5% pure by HPLC analysis. ^{14}C-Glyphosate was neutralized with NaOH, diluted with water to a concentration of 0.50 μg μl^{-1}, and stored at −20 C. MON 0818[3] (an ethoxylated tallowamine surfactant used in Roundup), glyphosate-isopropylamine salt[4] (MON 0139), and Roundup Original[5] were provided by Monsanto.

Uptake and Translocation Studies

Seed was germinated in soil (50/50 Metromix blend with fertilizer) in 10- by 10-cm pots in the greenhouse (32 C day and 25 C night with supplemental lighting). The average germination for seed was only about 30%. The labeled use rate of glyphosate for the control of *L. rigidum* in Australia is 0.2 to 0.4 kg ha^{-1} (Pratley et al. 1999). R and S *L. rigidum* (two to six leaves, 2 to 4 wk old) was presprayed with a high (1.26 kg ha^{-1}) or a low (0.28 kg ha^{-1}) dose of Roundup Original (187.1 L ha^{-1} spray volume). Just prior to spraying, the first leaf of the first tiller was covered with a wax paper sleeve to prevent interception of the spray solution. Immediately after the spray, the sleeve was removed, and a ^{14}C-glyphosate dosing solution was applied. The ^{14}C-glyphosate dosing solutions were prepared to match the volume, the surfactant concentration, and the glyphosate concentration of the spray solutions. A representative *L. rigidum* leaf blade was sprayed initially with water; the average volume of spray interception was 6 µl. Calculations showed that for the 0.28-kg ha^{-1} dose, the spray solution contained 0.03% MON 0818 and 1.5 µg ae $µl^{-1}$ glyphosate; the corresponding 1.26-kg ha^{-1} spray solution contained 0.14% MON 0818 and 6.8 µg ae $µl^{-1}$ glyphosate. ^{14}C-Glyphosate (782,000 dpm or 1.51 µg) was mixed with MON 0818 and MON 0139 so that in 6-µl volume, it contained the same surfactant and glyphosate concentrations as the spray solutions. The dose was applied as 6- by 1-µl drops to the adaxial leaf surface.

Following application of ^{14}C-glyphosate, plants were transferred to a growth chamber (12-h day/night, 29 C day, 25 C night, 60% humidity, 450 µE m^{-2} s^{-1} light). At harvest (6 DAT), the ^{14}C-treated leaf was excised at the base and spray washed with water then methanol (~10 ml each). The washes were pooled and analyzed for radioactivity. The treated leaf was then placed in a combustion cone. The rest of the plant was washed to remove soil from the roots. The plant was then separated into roots and shoots, and these tissues were placed in individual combustion cones that were dried overnight at 70 C.

Quantitation of Radioactivity

Analysis of tissue radioactivity was accomplished using a Packard 387 sample oxidizer with Oximate 80 robotics.[6] The oxidizer, which was routinely tested by combustion of standard samples, recovered > 98% of radioactivity with no carryover to successive samples. ^{14}C-Glyphosate in tissue was completely oxidized to $^{14}CO_2$, which was trapped in a liquid scintillation cocktail and quantitated by Tracor Analytic counters.[7] Based on initial applied radioactivity per plant, percentages were calculated for residues localized in the treated leaf. Total translocation of glyphosate into the plant was calculated by addition of radioactivity from the shoot and root sections. The sum of the localized, translocated, and leaf wash provided total radioactivity recovery.

We had planned to use 10 plants per treatment that were carefully matched in size and growth stage. But because of low and unpredictable germination, the actual number of replicates per treatment ranged from 5 to 20 plants. Because each plant was dosed and processed individually, uptake and translocation of glyphosate were calculated for each replicate plant. Average and standard errors were calculated from the replicates within a treatment.

Metabolism Studies

Plants (R and S) employed for these studies were treated the same as those in the uptake and translocation studies. Metabolism of glyphosate was examined in tissue extracts from the treated leaf, shoots, and roots of each plant. Tissues were initially minced into small pieces using scissors and homogenized using a Polytron tissue miser[8] in water (~0.75 ml). Homogenates were centrifuged (14,000 × *g* at 4 C for 25 min), and aliquots of supernatants were analyzed for radioactivity. Approximately 200- to 500-µl volumes of tissue extracts containing 30,000 to 200,000 dpm were analyzed by HPLC. Metabolites (glyphosate and aminomethyl phosphonic acid, AMPA) were identified based on retention times, and percentage distribution was quantified based on radioactivity.

HPLC Analysis

The HPLC system was assembled using components from Waters Associates[9] with a flow-through radioactivity detector from Radiomatics.[10] An Alltech strong anion exchange (SAX) column[11] (5 µm, 10 by 250 mm) was employed at a flow rate of 3 ml min^{-1}. The solvent gradient employed two buffers, 5 and 100 mM KH_2PO_4, pH 2.0 with 4% methanol. The gradient was programmed as follows: 5 mM (100%) for 2 min, 5 to 100 mM (100%) linearly in 3 min, and 100 mM for 10 min. The radioactivity detector (RAD) employed a scintillant[12] at a flow rate of 9 ml min^{-1}. Mixtures of ^{14}C-standards were routinely analyzed prior to sample analyses. The following retention times were typically obtained: AMPA, 5.5 min; glyphosate, 11.5 min; and N-acetyl AMPA, 14.4 min.

Autoradiography Studies

Plants used for these studies were treated the same as those in uptake and translocation studies. R and S plants (four each) were presprayed with glyphosate at 0.28 kg ae ha^{-1}, and the shielded leaf was treated with a ^{14}C-glyphosate solution. Plants were maintained in the growth chamber and harvested 2 and 5 DAT. Plants were washed, pressed, dried, and exposed to x-ray film[13] at −80 C for 4 d.

Results and Discussion

Significant resistance to glyphosate was demonstrated in R plants during spray titration studies (Pratley et al. 1996, 1999). While S plants were completely killed at < 0.22 kg ae ha^{-1} of glyphosate, the R plants had 93% survival. Furthermore, 30% of R plants were unaffected by a treatment of 0.43 kg ae ha^{-1} glyphosate.

Uptake and Translocation Studies

Both R and S plants were presprayed with a high or low rate of formulated glyphosate followed by manual application of ^{14}C-glyphosate to the first leaf of the first tiller, which was shielded from the spray. Even though the glyphosate dose varied, all plants received the same amount of radioactivity.

TABLE 1. Total recovery and uptake of ^{14}C-glyphosate in R and S rigid ryegrass (*L. rigidum*) 6 DAT.

Biotype (*n* reps)	Rate (kg ae ha^{-1})	Fractions	^{14}C-Glyphosate as % appl dose (average ± SE)
R (20)	1.26	Total recovery	97.3 ± 1.5
		Uptake	79.2 ± 4.0
		Leaf wash	18.1 ± 4.4
S (5)		Total recovery	96.1 ± 5.3
		Uptake	78.0 ± 4.2
		Leaf wash	18.1 ± 3.4
R (7)	0.28	Total recovery	92.1 ± 5.5
		Uptake	64.7 ± 6.2
		Leaf wash	27.4 ± 6.4
S (10)		Total recovery	90.2 ± 3.9
		Uptake	64.0 ± 6.0
		Leaf wash	26.2 ± 7.0

Total recoveries of applied radioactivity 6 DAT were calculated for the replicates within each treatment and averaged from 90.2 ± 3.9 to 97.3 ± 1.5% (Table 1). Based on the excellent radioactivity recovery, all calculations are reported as percentages of applied dose. Total plant uptake was nearly identical for R and S plants within the same treatment dose. At the high dose (1.26 kg ae ha^{-1}), uptake in R and S plants was 79.2 ± 4.0 and 78.0 ± 4.2%, respectively. At the low dose (0.28 kg ae ha^{-1}), uptake in R and S was 64.7 ± 6.2 and 64.0 ± 6.0%, respectively. The high dose demonstrated slightly higher uptake, presumably due to the higher surfactant and glyphosate concentration in the dosing solution. Glyphosate not recovered from plants was recovered in the treated leaf wash. Recovery ranged from 18.1 ± 4.4 to 27.4 ± 6.4% of the applied dose.

Table 2 shows the distribution of radioactivity into plant tissues, which included the treated leaf, roots, and shoots. Radioactivity in the treated leaf represented glyphosate that was loaded into the leaf (and hence, not removed by the wash) but not translocated in the plant. Once again, little to no difference was detected between the R and S plants in radioactivity localized in the treated leaf. For both R and S, the high dose localized more radioactivity (45.1 ± 4.4 and 45.1 ± 6.2%, respectively) than the low dose (26.4 ± 6.1 and 28.8 ± 7.0%, respectively). Total translocation of glyphosate was similar in R and S plants and ranged from 18.1 ± 2.2 to 22.6 ± 2.2% in shoots and from 13.6 ± 2.0 to 15.8 ± 2.6% in roots. In contrast to uptake, similar translocation was observed at both high and low doses of glyphosate. These results indicate that although uptake was higher at the high dose, increased localization of glyphosate in the treated leaf resulted in comparable translocation as the low dose. The high dose not only contained more glyphosate but also more surfactant. We speculate that the high surfactant concentration caused greater tissue injury in the treated leaf, thus negatively affecting translocation (Feng et al. 1998). The conclusion is that there is little to no difference in glyphosate uptake and translocation between R and S plants.

Autoradiography Studies

The translocation results provided a quantitative but gross distribution of glyphosate in shoots and roots. Autoradiography studies were conducted to provide a more detailed, albeit qualitative analysis of tissue distribution. R and S plants, as in the above studies, were presprayed with 0.28 kg ha^{-1} glyphosate followed by treatment with ^{14}C-glyphosate dosing solution. R and S plants visualized 2 and 5 DAT demonstrated little difference in tissue distribution. In general, the highest concentration of glyphosate was observed in the treated leaf, followed by other leaves of the same tiller, and then leaves of other tillers. Roots proximate to the treated leaf received more glyphosate. Young shoots and the crown showed more glyphosate than the older tillers and leaves. Translocation of glyphosate in both R and S *L. rigidum* appeared similar to other plants (Klevorn and Wyse 1984; Wallace and Bellinder 1995) and proceeded from source to sink tissues (Franz et al. 1997).

TABLE 2. Translocation of ^{14}C-glyphosate to shoots and roots of R and S rigid ryegrass (*L. rigidum*) 6 DAT.

Biotype (*n* reps)	Rate (kg ae ha^{-1})	Tissue fractions	^{14}C-Glyphosate as % appl dose (average ± SE)
R (20)	1.26	Shoot	18.1 ± 2.2
		Root	16.0 ± 1.6
		Total translocation	34.2 ± 3.4
		Treated leaf	45.1 ± 4.4
S (5)		Shoot	19.3 ± 2.4
		Root	13.6 ± 2.0
		Total translocation	32.9 ± 3.9
		Treated leaf	45.1 ± 6.2
R (7)	0.28	Shoot	22.6 ± 2.2
		Root	15.7 ± 4.6
		Total translocation	38.3 ± 5.7
		Treated leaf	26.4 ± 6.1
S (10)		Shoot	19.3 ± 3.3
		Root	15.8 ± 2.6
		Total translocation	35.2 ± 5.6
		Treated leaf	28.8 ± 7.0

Metabolism Studies

These studies employed plants that were treated the same as those in the uptake and translocation studies. Instead of combustion, the tissues were homogenized and extracts analyzed by SAX-HPLC/RAD. Tissues (roots, shoots, and the treated leaf) from individual R and S plants were harvested 6 DAT and analyzed.

HPLC was calibrated with a mixture of ^{14}C standards including glyphosate and AMPA. Analysis of the dosing solution showed two peaks identified based on retention time as glyphosate (83.6%) and AMPA (12.7%) (Table 3). Al-

TABLE 3. Distribution of radioactivity as glyphosate or AMPA in tissue extracts of R and S rigid ryegrass (*L. rigidum*) as determined by SAX-HPLC 6 DAT.

Biotype (*n* reps)	Rate (kg ae ha^{-1})	Fractions	^{14}C-Glyphosate as % distribution (average ± SE)
Dosing solution	None	Glyphosate	83.6
		AMPA	12.7
R (9)	1.26	Glyphosate	78.4 ± 2.4
		AMPA	16.6 ± 2.0
S (6)	0.28	Glyphosate	86.5 ± 1.8
		AMPA	12.2 ± 1.8

though the purity of the original ^{14}C-glyphosate was very high (99.5%), storage of glyphosate as a dilute water solution at −20 C must have caused some degradation to AMPA over time. Analysis of tissue extracts (treated leaf, roots, and shoots) from R and S plants consistently displayed two major peaks identified as glyphosate and AMPA. Because no difference in distribution was detected among various tissues of plants, we averaged all the results within R and S biotypes (Table 3). The distribution of radioactivity between glyphosate and AMPA in R plants was 78.4 ± 2.4 and 16.6 ± 2.0%, respectively. In comparison, the distribution in S plants was 86.5 ± 1.8 and 12.2 ± 1.8% for glyphosate and AMPA, respectively. Although R plants showed slightly lower glyphosate and higher AMPA than S plants, this minor difference in composition is believed to be insufficient to account for the level of resistance observed in whole plants. Previous work using Roundup Ready *Glycine max* (L.) Merr. (soybean) and *Brassica napus* L. (canola) seedlings containing the glyphosate degradation gene (Barry et al. 1992) showed almost complete conversion of glyphosate to AMPA within a few days after treatment (unpublished data).

The results of these studies demonstrated similar patterns of glyphosate uptake, translocation, and metabolism in R and S biotypes. *Lolium rigidum* plants displayed extensive uptake of glyphosate (~70% of the applied dose). About one-half of the absorbed dose was exported from the treated leaf into the plant, with nearly equal distribution between shoots and roots. Our results suggest that neither uptake, translocation, nor metabolism play a major role in glyphosate resistance in *L. rigidum*.

Powles et al. (1998) recently reported evolved resistance to glyphosate in *L. rigidum* in an orchard in Australia; the mechanism of resistance is currently under investigation. Through recurrent selection, glyphosate resistance has also been demonstrated in *Lolium perenne* L. (perennial ryegrass), although the mechanism remains unknown (Johnston and Faulkner 1991). The mechanism of glyphosate resistance has also been examined in sensitive and resistant *Convolvulus arvensis* L. (field bindweed). Neither absorption nor translocation could account for differential sensitivity of R and S biotypes to glyphosate (Westwood et al. 1997). Further studies demonstrated increased shikimate pathway activity and higher concentration of phenolics in R than in S plants (Westwood and Weller 1997). The authors concluded that multiple mechanisms at cellular and metabolic levels accounted for glyphosate resistance in *C. arvensis*. Our own investigations in *L. rigidum* are also progressing toward cellular or biochemical mechanisms of resistance. Studies are underway to determine the sensitivity of EPSPS (5-enolpyruvyl-shikimate-3-phosphate synthase) to glyphosate and the overexpression of EPSPS as potential mechanisms of resistance in *L. rigidum*.

Sources of Materials

[1] R and S *L. rigidum* seed, Dr. Jim Pratley, Charles Sturt University, Wagga Wagga, Australia.
[2] Radiolabeled glyphosate, New England Nuclear, Boston, MA.
[3] MON0818, Monsanto Co., St. Louis, MO.
[4] Glyphosate isopropylamine salt (MON0139), Monsanto Co., St. Louis, MO.
[5] Roundup Original, Monsanto Co., St. Louis, MO.
[6] Packard 387 sample oxidizer with Oximate 80 robotics, Packard, Downers Grove, IL.
[7] Tracor Analytic counters, Austin, TX.
[8] Polytron tissue miser, Brinkman, Westbury, NY.
[9] HPLC system components, Waters Associates, Marlborough, MA.
[10] Flow-through radioactivity detector, Radiomatics, Downers Grove, IL.
[11] Alltech SAX column, Allsphere, Deerfield, IL.
[12] Atomflow scintillant, DuPont, Boston, MA.
[13] Biomax MR x-ray film, Kodak, Rochester, NY.

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Adoption of Best Management Practices to Control Weed Resistance by Corn, Cotton, and Soybean Growers

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This study examined adoption of 10 best management practices (BMPs) to control weed resistance to herbicides using data from a survey of more than 1,000 US corn, cotton, and soybean growers. Count-data models were estimated to explain the total number of BMPs frequently practiced. Ordered-probit regressions were used to explain the frequency of individual BMP adoption. Growers practicing a greater number of BMPs frequently had more education, but less farming experience; grew cotton; expected higher yields relative to the county average; and farmed in counties with a lower coefficient of variation (CV) for yield of their primary crop. Yield expectations and variability were significant predictors of adoption of individual BMPs. Most growers frequently adopted the same seven BMPs. Extension efforts may be more effective if they targeted the three practices with low adoption rates. Counties with a high-yield CV would be areas to look for low BMP adoption.

Key words: weed, herbicide, resistance management, corn, cotton, soybeans, adoption.

Introduction

In 2008, agricultural producers planted more than 80% of US cotton and corn acreage and more than 90% of soybean acreage to transgenic glyphosate-tolerant, Roundup Ready® (RR) seed varieties (US Department of Agriculture Agricultural Marketing Service [USDA AMS], 2008; USDA National Agricultural Statistics Service [NASS], 2008). Many studies report significant pecuniary and non-pecuniary benefits to growers from using glyphosate-resistant varieties (Gianessi, 2008; Marra, Pardey, & Alston, 2002; Marra & Piggott, 2006; Mensah, 2007; Piggott & Marra, 2008).

The evolution of glyphosate-resistant weeds threatens the sustainability of these benefits, however. The number and range of glyphosate-resistant weeds has been increasing in the United States since commercialization of RR crops (Heap, 2009). The evolution of weed resistance to herbicides also poses problems for other herbicide-resistant crops, such as LibertyLink® or Clearfield® crops. The potential for pests or weeds to develop resistance in response to frequent applications of a narrow set of chemicals with the same mode of action is well established in the literature (Carlson & Wetzstein, 1993; Holt & Lebaron, 1990; Powles & Shaner, 2001; Shaner, 1995). Beckie (2006, pp. 793) identifies, "recurrent application of highly efficacious herbicides with the same site of action" and "annual weed species that occur in high population densities" as key risk factors for the evolution of herbicide resistance in weeds.

However, strategies for reducing the risk of pest resistance are also well-documented (Burgos et al., 2006; Culpepper, York, & Kichler, 2008; Gressel & Segel, 1990; Monsanto, 2009a, 2009b; Mueller, Mitchell, Young, & Culpepper, 2005; Nalewaja, 1999; Prather, DiTomaso, & Holt, 2000; Steckel, Hayes, & Rhodes, 2004; Stewart, 2008). Commodity groups, extension specialists, and Monsanto have recommended that growers adopt various best management practices (BMPs) to prevent or delay the spread of glyphosate-resistant weeds (Burgos et al., 2006; Culpepper et al., 2008; Monsanto, 2009a, 2009b; Steckel et al., 2004; Stewart, 2008). These strategies fall under the more general rubric of integrated weed management (IWM), components of which include weed scouting; avoidance on over-reliance on a compound or compounds with a single mode of action against weeds; preventing herbicide-resistant gene spread, non-chemical control such as tillage, and crop rotations. A key element of this strategy is diversifying herbicides used, relying on multiple compounds with different modes of action.

This study examines the frequency of grower adoption of 10 different BMPs to prevent or delay weed resistance. Primary survey data on more than a thousand US corn, cotton, and soybean growers was used to characterize the nature of BMP adoption. Count-data models were estimated to explain the total number of BMPs frequently practiced. Ordered-probit regressions were used to explain the frequency of individual BMP adoption.

Previous Studies

There are four strands of literature pertinent to the understanding of grower adoption of BMPs. First, weed science studies describe how weed resistance to herbicides evolves, the approaches to prevent and respond to resistance, and the roles of different BMPs in prevention and response (e.g., Beckie, 2006; Green, 2007). These are not economic studies *per se*, but do consider economic incentives and trade-offs. Second are normative, economic modeling approaches (e.g., Gorddard, Pannell, & Hertzler, 1995; Llewellyn, Lindner, Pannell, & Powles, 2001; Pannell & Zilberman, 2001; Weersink, Llewellyn, & Pannell, 2005). Here, the susceptibility of weeds to herbicides is examined as an exhaustible resource. Growers face an intemporal trade-off between weed-management practices that maximize short-run returns versus practices that delay resistance. Delaying resistance may be less profitable in the short-run, but more profitable in the long run. Third, positive, empirical analyses collect and analyze data on grower perceptions and behavior regarding weed resistance (e.g., Hammond, Luschei, Boerboom, & Nowak, 2006; Johnson & Gibson, 2006; Wilson, Tucker, Hooker, LeJeune, & Doohan, 2008). While the economic models highlight how growers *should* manage resistance, these empirical studies examine what steps growers *actually take* to manage it. These studies also shed light on grower rationales for their behavior. Fourth, there is the econometric approach (Llewellyn et al., 2007). The first step in this approach is to develop a dynamic economic model of weed management, including resistance management. Results from the theoretical model guide variable selection and statistical specification for multivariate regression analysis. Finally, the multivariate regression analysis tests hypotheses generated from the theoretical model. Thus, the prescriptive, theoretical model informs specification of the descriptive, statistical model. In turn, statistical model results test the validity of and hypotheses generated by the theoretical model.

Conceptual Framework

Following Llewellyn et al. (2001, 2007), we treat the adoption of weed resistance BMPs as a dynamic optimization problem. A grower chooses application rates of a preferred herbicide, H_t, and adoption of different BMPs, $\boldsymbol{M}_t$, to maximize the net present value (NPV) of returns.

$$\text{Max } NPV = \sum_{t=0\ldots n} \{P_t Y_t[1 - \delta_t(N_t, R_t, H_t, \boldsymbol{M}_t)] - C_H H_t - C_M(M_t) - V_t\}\,\beta \quad (1)$$

with respect to H_t, $\boldsymbol{M}_t$, subject to

$$R_t - R_{t-1} = f(N_t, R_t, H_t, \boldsymbol{M}_t, X_t);\ \partial f/\partial H_t > 0;\ \partial f/\boldsymbol{M}_t < 0;\ \partial f/X_t > 0, \quad (2)$$

where

P_t = crop price
Y_t = crop yield
δ_t = percent yield loss from weed damage
N_t = pre-treatment weed population
R_t = weed resistance to the herbicide
H_t = level of herbicide use
$\boldsymbol{M}_t$ = vector of resistance management practices
X_t = behavior of neighbors or external factors that increase resistance
C_H = cost of herbicide treatment
C_M = cost of resistance management
V_t = other variable costs
β = discount factor

Equation 2 characterizes the evolution of resistance. Initially, use of the herbicide reduces damage ($\partial\delta_0/\partial H_t < 0$), but also increases resistance ($\partial f/\partial H_t > 0$). Evolution of resistance renders the herbicide less effective ($\partial^2\delta_0/\partial H_t\,\partial R_t > 0$). Resistance-management BMPs, $\boldsymbol{M}_t$, slow the evolution of resistance ($\partial f/\boldsymbol{M}_t < 0$), but entail additional costs, $C_M(\boldsymbol{M}_t)$. BMPs may reduce damage in the current period ($\partial\delta_t/\partial\boldsymbol{M}_t < 0$). However, these alternatives may be less effective or more expensive than frequent applications of the preferred herbicide. For example, repeated applications of glyphosate may be more profitable (at least in the short-run) than applying tank mixes or additional residual herbicides.[1] Many growers manage herbicide-resistant crops in combination with no-till practices. While supplemental tillage offers the option of non-chemical control, it would require growers to forego some benefits of no-till systems (such as reduced fuel costs or soil erosion).

This stylized model captures key features of weed BMP adoption. First, BMPs are costly to adopt. Yet they

1. *The model presented here treats use of multiple herbicides with different modes of action as part of the set of BMPs in $\boldsymbol{M}_t$. A more complete, but more complicated, model could consider resistance evolution of different classes of herbicides, not just the preferred herbicide. This would involve multiple equations such as f(), but could allow for examination of the "optimal rotation" of herbicides.*

slow resistance and can, in some cases, substitute for herbicide applications in reducing current damage. Thus, some BMPs may be profitable to adopt apart from their contribution to resistance management. If BMPs reduce current profitability, however, growers will not adopt them unless (a) they effectively slow resistance, (b) their contribution to future profitability counteracts their short-run costs, and (c) growers recognize the BMPs' contribution to future profitability.

Even if the damage function $\delta()$ and resistance-evolution equation $f()$ are such that adoption of BMPs increases the NPV of long-run profits, growers may still not adopt them. Growers must have sufficient information about $\delta()$ and $f()$ to expect that their own adoption of BMPs is profitable in the long run. A potential role of extension is to increase knowledge about $\delta()$ and $f()$. There is more scope for individual growers learning about the effect of practices on current weed damage, $\delta()$, than on the evolution of resistance, $f()$. High variability in production outcomes, however, may make such learning more difficult.

Another factor affecting grower adoption is whether growers perceive weed resistance to be subject to their own control. Pannell and Zilberman (2001) have argued that resistance management is subject to greater individual control than insect pest management, indicating that common pool externalities discouraging resistance management should be less of a problem. If, however, growers perceive that resistance depends on external factors rather than their own actions (i.e., the effect of $\partial f / X_t$ dominates the effect of $\partial f / M_t$), this will discourage BMP adoption. In a study of Ohio farmer perceptions of weed management, Wilson et al. (2008) found growers attributed weed introduction and spread to external natural factors and neighbor behavior. At the same time, they placed less emphasis on the importance of their own actions.

The evolution of resistance may also spur adoption of BMPs. As resistance to an herbicide develops, relying solely on that herbicide becomes less effective at managing weeds. In effect, as $\partial \delta_t / \partial H_t$ approaches zero, growers may be forced to shift to other weed-control methods. Various studies suggest that development of herbicide-resistant weeds in Australia and Canada has spurred greater adoption of BMPs (Llewellyn et al., 2004; Powles, Preston, Jutsum, & Bryan, 1997; Wilson et al., 2008). Thus, one may see use of BMPs not to prevent resistance but as a means of mitigating it.

This simple model suggests testable hypotheses. First, growers will be more likely to adopt BMPs that have immediate benefits in terms of controlling current weed populations. Second, this effect will be stronger for growers with higher potential yields because percent reductions in damage have a higher payoff. In contrast, growers will be less likely to adopt practices that do not provide obvious, short-run benefits. Third, growers experiencing resistance problems may increase BMPs as their traditional means of control becomes less effective. Fourth, implementing complex, interrelated BMPs may require more human capital. So, one may expect more use of BMPs among growers with more education. Greater education helps lower costs of implementing BMPs (C_H). Fifth, greater variability in agronomic and economic outcomes may discourage BMP adoption. Pannell and Zilberman (2001) note the importance of observability and trialability in encouraging adoption of new technologies. In areas with highly variable production outcomes, growers may have more difficulty assessing the effects of and returns to BMP adoption.

Data

Data were collected via a telephone survey conducted by Marketing Horizons for Monsanto in November/December of 2007. The survey was designed to be a random, representative sample of corn, cotton, and soybean growers from the Great Plains eastward. Data collection was restricted to farms with 250 or more acres of the targeted crop. Responses were obtained from 401 cotton growers, 402 corn growers, and 402 soybean growers. While growers were "targeted" to respond to questions about a particular crop, they often also produced other crops. For example, many cotton growers who were asked detailed questions about cotton production also grew corn or soybeans.

The survey included four sections. The first asked questions about operator and farm characteristics. These included operator education and experience, acres operated, percentage of operated land owned, acres of different crops grown, acreage planted with herbicide-tolerant crops, crop-rotation practices, and extent of livestock production. The second section asked growers about their current weed management; adoption of weed-resistance BMPs; herbicides and/or tillage used for pre-plant, pre-emergent, and post-emergent weed control; and timing and frequency of post-emergent weed management. The third section asked growers about their attitudes regarding various weed-management concerns, such as crop yield, crop-yield risk, crop price, crop-price risk, herbicide costs, seed costs, overhead costs, labor and management time, crop safety, operator and worker safety, environmental safety, erosion control, and conve-

Table 1. Frequency of weed resistance best management practice (BMP) adoption (percent of respondents practicing).

BMP	Always	Often	Sometimes	Rarely	Never
Scout before	57%	26%	11%	3%	2%
Scout after	51%	29%	15%	2%	1%
Clean field	60%	14%	13%	5%	8%
Control early	54%	35%	9%	1%	0%
Control escapes	45%	34%	15%	4%	2%
Clean equipment	15%	11%	20%	22%	31%
New seed	87%	7%	3%	1%	2%
Different modes	18%	21%	33%	15%	13%
Supplemental tillage	11%	10%	26%	21%	32%
Use label rate	74%	19%	4%	1%	0%

nience. The fourth section asked growers about the cost of their weed-management program and the value of the benefits they derived using a RR weed-management program.

For this study, weed-resistance management practices were categorized into 10 separate BMPs:

1. Scouting fields before applying herbicides
2. Scouting fields after herbicide applications
3. Start with a clean field, using either a burndown herbicide application or tillage
4. Controlling weeds early when they are relatively small
5. Controlling weed escapes and preventing weeds from setting seeds
6. Cleaning equipment before moving from field to field to minimize spread of weed seed
7. Using new commercial seed that is as free from weed seed as possible
8. Using multiple herbicides with different modes of action
9. Using tillage to supplement herbicide applications
10. Using the herbicide-label recommended application rate

Growers could choose among five responses when asked how frequently they adopted a BMP: (1) always, (2) often, (3) sometimes, (4) rarely, and (5) never. (Growers could respond, "don't know," but these accounted for 0.3% of responses). Six BMPs were always practiced by a majority of growers (Table 1). There were three BMPs, however, that a significant share of growers never practiced. These included cleaning equipment before moving between fields (31%), using multiple herbicides with different modes of action (13%), and using supplemental tillage (32%).

Table 2. Frequency of weed resistance BMP adoption (percent of respondents).

BMP	Often or always	Sometimes	Rarely or never
Scout before	83%	11%	5%
Scout after	81%	15%	4%
Clean field	75%	13%	12%
Control early	89%	9%	2%
Control escapes	79%	15%	6%
Clean equipment	25%	20%	54%
New seed	94%	3%	2%
Different modes	39%	33%	28%
Supplemental tillage	21%	26%	53%
Use label rate	93%	4%	1%

Table 2 combines the share of BMPs practiced often or always, then rarely or never for the same data. There are seven practices that 75% of growers practice frequently (often or always; Table 2): use new seed (94%), follow label rate (93%), start with a clean field (75%), scout before (83%), scout after (81%), control weeds early (89%), and control weed escapes (79%). Again, one can see that the remaining three BMPs—using multiple herbicides with different modes of action, cleaning equipment, and supplemental tillage —were practiced less frequently (Table 2).

Adoption patterns were remarkably similar across producer groups. Seven of the BMPs were practiced by 71% or more of corn, cotton, or soybean producers (Figures 1a, 1b, 1c). Moreover, these were the same seven practices. All three of the producer groups used multiple herbicides with different modes of action, cleaned equipment, or practiced supplemental tillage much less frequently. Less than half of any of these producers practiced these three BMPs often or always. More corn producers used multiple herbicides with different modes

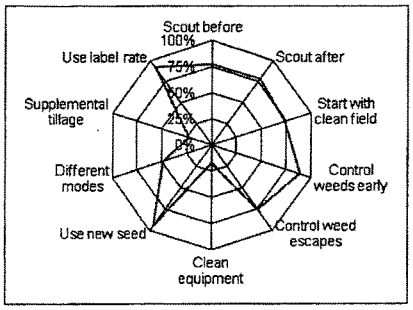


Figure 1a. Percent of corn growers adopting BMPs often or always.

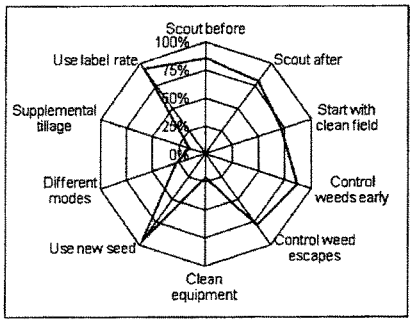


Figure 1b. Percent of soybean growers adopting BMPs often or always.

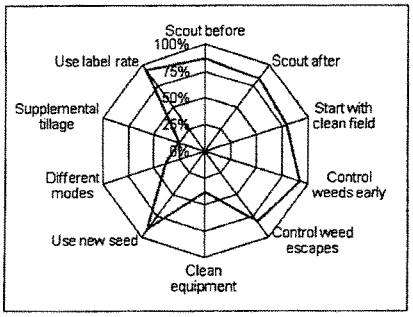


Figure 1c. Percent of cotton growers adopting BMPs often or always.

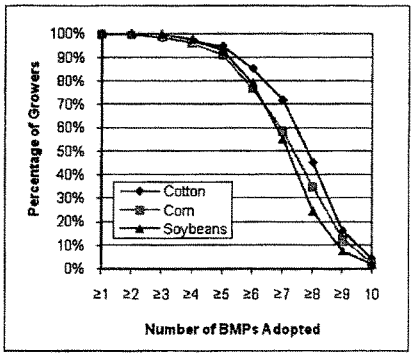


Figure 2. Percentage of growers often or always adopting BMPs by total number of BMPs adopted and targeted crop.

of action often or always (49%) than either cotton (38%) or soybean (28%) growers.

Cotton growers were more likely to practice more BMPs often or always than were corn or soybean growers (Figure 2). More than 70% of cotton growers practice seven or more BMPs often or always, compared to 58% of corn producers and 55% of soybean producers. About 45% of cotton growers practiced eight or more BMPs often or always compared to 35% for corn growers and 24% for soybean growers. About 95% of cotton growers often or always adopted five or more BMPs.

Methods

Integrated weed management (IWM) involves adoption of multiple, interrelated practices. For empirical research, this raises questions about how one measures adoption when "adoption" involves making selections from a suite of different practices. Some studies consider adoption of individual practices, while others attempt to develop indexes characterizing the intensity of adoption. Hollingsworth and Coli (2001) developed a scoring system based on a weighted sum of practices adopted. Hammond et al. (2006) used an index that was an unweighted count of the total number of practices adopted. Llewellyn et al. (2007) considered those growers who adopted three or more practices (out of a possible six) as IWM adopters.

We analyzed data concerning BMP adoption in two ways. First, multivariate count-data analysis was used to identify which factors explained the total number of BMPs a grower adopted frequently (often or always).

For example, which factors help predict whether a grower will adopt eight practices frequently as opposed to seven? Here ,the dependent variable is similar to the unweighted index approach of Hammond et al. (2006). Next, multivariate ordered-probit regressions were estimated to identify factors that help explain how frequently a grower practiced a particular, single BMP.

For the multivariate regression analyses, in addition to the Marketing Horizons survey data, county-specific variables were created using data from the USDA NASS. These included the coefficient of variation (CV) of county crop yields of the targeted crop. CV is the standard deviation of yields divided by the mean of yields over 10 years. The yield CV was included to test the hypothesis that growers in counties with greater yield risk had different patterns of BMP adoption. Growers were asked what they expected their target crop yields would total. An index was created that was the ratio of growers' expected yields to their counties' average yields. This variable was included to test the hypothesis that growers with higher-than-average yields (perhaps better managers or growers farming under conditions that are more favorable) were more likely to adopt BMPs more frequently.

The number of BMPs a grower adopts often or always can only be an integer from 0, 1, 2, ... up to 10. This means a Poisson (or other count data) model is more appropriate than standard linear regression, which can yield parameter estimates that are inefficient, biased, or both and can yield nonsensical predicted values (Greene, 1997; King, 1988). A Poisson regression assumes that the mean and variance of the dependent variable are equal. This assumption can overestimate the statistical significance of regression parameter estimates when there is over-dispersion (variance greater than the mean) or underestimate their statistical significance when there is under-dispersion (variance less than the mean). However, estimation here followed McCullagh and Nelder (1989), who fit a Poisson regression that relaxes this restriction. McCullagh and Nelder use the Pearson chi-square method to estimate a scale parameter s, such that $s = 1$ if the mean and variance are equal, $s > 1$ if the variance exceeds the mean (over-dispersion), and $s < 1$ if the variance is less than the mean (under-dispersion). We also estimate a generalized negative binomial regression as an alternative to a Poisson regression because it also allows for separate estimation of mean and variance (Cameron & Trivedi, 1998; Greene, 1997).

Next, ordered-probit regressions were estimated separately for each of the 10 BMPs. When asked how frequently they adopted a given BMP, respondents could answer 1-always, 2-often, 3-sometimes, 4-rarely, or 5-never. In addition, respondents could answer "don't know," but few responded this way, so we deleted these few observations from the regression analysis.

Table 3. Descriptive statistics for variables used in regressions.

	Means	St. dev.
Number of BMPs practiced often or always	6.838	1.540
Corn producer (=1 if targeted producer; = 0 otherwise)	0.342	
Soybean producer (=1 if targeted producer; = 0 otherwise)	0.355	
Cotton producer (=1 if targeted producer; = 0 otherwise)	0.303	
Years of education	14.042	1.816
Years farming	29.799	12.116
Crop acreage (acres)	1422	1196
Percent of land owned	41.611	32.060
Raises livestock (=1 if yes; = 0 otherwise)	0.368	
Percent RR (percent of targeted crop planted to RR varieties)	87.026	28.275
Yield difference (percent difference of grower's expected targeted crop yield compared to county 10-year average)	29.559	44.120
Yield CV (county 10-year coefficient of variation of targeted of yield of grower's targeted crop)	0.177	0.084
Resistance concern (=1 if yes if grower indicated weed resistance was a concern; = 0 otherwise)	0.516	
Herfindahl index (Measure of crop specialization = 1 for complete specialization; minimum value of 0.25)	0.536	0.160
Custom applications (percent of herbicide applications to targeted crop made by custom applicators)	28.577	41.871
County resistance (=1 if weed resistance reported in county; = 0 otherwise)	0.126	
CRD resistance (percent of counties in 'crop reporting' with reports of weed resistance)	8.932	20.679
Number of observations	1,006	

Source: Marketing Horizons Survey and NASS county-level yield data.

Table 4. Count data regression results for the number of weed BMPs adopted often or always.

	State effects				No state effects			
	Poisson		Negative binomial		Poisson		Negative binomial	
Variable	Coeff.	Signif.	Coeff.	Signif.	Coeff.	Signif.	Coeff.	Signif.
Intercept	**1.798**	**0.000**	**1.797**	**0.000**	**1.797**	**0.000**	**1.796**	**0.000**
Soybean	-0.009	0.640	-0.01	0.623	-0.016	0.393	-0.015	0.396
Cotton	***0.080***	***0.100***	0.079	0.111	**0.074**	**0.002**	**0.073**	**0.003**
Raise livestock	-0.002	0.913	-0.002	0.89	-0.006	0.686	-0.006	0.696
Resist concern	0.005	0.756	0.006	0.704	0.006	0.69	0.006	0.667
County weed resistance	0.047	0.172	0.048	0.169	0.050	0.142	0.050	0.147
Education	**0.011**	**0.010**	**0.011**	**0.010**	**0.012**	**0.003**	**0.012**	**0.003**
Years farming	***-0.001***	***0.059***	***-0.001***	***0.058***	-0.000	0.143	-0.000	0.15
Crop acres	0.0000	0.148	0.00001	0.134	***0.00001***	***0.085***	***0.00001***	***0.084***
% land owned	0.000	0.304	0.000	0.27	0.000	0.252	0.000	0.239
RR acres	0.000	0.53	0.000	0.522	0.000	0.532	0.000	0.514
Yield diff	**0.0000**	**0.037**	**0.0000**	**0.035**	***0.0000***	***0.054***	**0.0000**	**0.048**
Yield CV	**-0.358**	**0.006**	**-0.366**	**0.006**	**-0.314**	**0.007**	**-0.319**	**0.007**
Herfindahl	0.074	0.124	0.073	0.135	0.056	0.22	0.056	0.229
% custom ap.	0.000	0.489	0.000	0.519	0.000	0.580	0.000	0.588
CRD weed Rst	**-0.002**	**0.016**	**-0.002**	**0.015**	***-0.001***	***0.053***	***-0.001***	***0.057***
IL*	**0.057**	**0.040**	**0.058**	**0.038**				
IN	**0.078**	**0.042**	**0.078**	**0.043**				
KS	**0.179**	**0.001**	**0.182**	**0.001**				
s (Scale)	0.332		0.043		0.335		0.043	
Likelihood ratio test statistic	91.302	0.000	90.689	0.000	61.875	0.000	61.168	0.000
d.f.	32		32		15		15	

** Only significant state effects reported. Boldface denotes significance at 5% level. Boldface with italics denotes significant at 10% level.*

The set of covariates used in the regression models included (1) dummy variables for target crop grown and whether a grower sold livestock; (2) years of grower education and farming experience; (3) total crop acres and percent of cropland owned; (4) the percentage of target crop planted to RR seed varieties in the previous year; (5) percent of herbicide applications carried out by a custom applicator; (6) a Herfindahl index based on the proportion of the crop acreage planted to corn, cotton, soybean, and other crops, which increases as a grower becomes more specialized; (7) a dummy variable indicating that the grower listed weed resistance as a concern in an open-ended question about weed management concerns—growers were not asked directly if resistance was a concern; (8) grower expected yield as a percent of county average yield and the coefficient of variation of target crop yield in the grower's county; and (9) measures of reported herbicide resistance. Two measures of reported herbicide resistance were constructed based on proprietary data obtained from Monsanto. These were (a) a dummy variable indicating weed resistance to herbicides has been reported in a grower's county and (b) the percentage of counties in a grower's crop reporting district where weed resistance has been reported.

Table 3 reports descriptive statistics for variables used in the regressions. The sample included 1,006 observations after deleting those observations with missing data. Adoption rates of RR varieties are high, with an average of 87% of the acres of targeted crops planted to those varieties. Grower yield expectations also seem high relative to county averages. On average, growers expected their yields to exceed their county's 10-year average by 29%. This may reflect optimism on the part of producers, but recall that (a) growers were surveyed about their primary crop, and (b) our sample includes larger producers, only those growing 250 or more acres of the targeted crop. So, it might not be too surprising that relatively large growers, specializing in production of a crop expect

higher-than-average yields. Or, growers' responses may reflect their potential yield, perhaps reflecting the highest yield they obtained in recent years.

Results—Count-Data Analysis

Table 4 reports count-data regression results where the dependent variable is the total number of weed BMPs that a grower reported using either often or always. Table 4 reports results for generalized Poisson and negative binomial regressions with and without state fixed effects. The Poisson and negative binomial specifications yield similar results, with both models suggesting under-dispersion. Based on the likelihood statistics, we can reject the hypothesis of no state-level effects. However, only three states individually had statistically significant effects. The default state is Iowa, and the regression coefficients for Illinois, Indiana, and Kansas were all positive and significant. This suggests that, compared to Iowa, growers in these states tend to practice more BMPs often or always, while growers in other states tend to practice about the same number of weed BMPs as Iowa's growers.

A number of variables were significant across all specifications. The number of BMPs adopted

- increased with a grower's level of education,
- increased for growers with expected yields greater than the county average yield,
- was lower in counties with more variable yields (measured by the county yield CV), and
- was lower in crop- reporting districts reporting more resistance problems.

In regressions with state effects, the number of years of farming experience was negatively associated with the number of BMPs adopted, suggesting that younger farmers tend to adopt more BMPs. Separate models estimated by target crop did not perform well and so are not reported here—for the separate corn and soybean models, the null hypothesis of all zero coefficients (except for the constant) could not be rejected at the 5% level of significance.

In sum, younger, more educated growers who expect to obtain higher-than-average yields practiced a greater number of BMPs often or always. Growers in regions with greater percentage yield variability practiced fewer BMPs. The relationship between local resistance episodes and grower BMP adoption was mixed. Growers in crop-reporting districts with more counties reporting resistance practiced fewer BMPs. Yet, growers farming in counties reporting resistance, tended to adopt more BMPs. This latter relationship was not significant, however.

Cotton growers and larger operators appeared to adopt more BMPs, but this affect was attenuated by including state-specific effects. The attenuating effect of state variables may come from the fact that there was no overlap of growers in surveyed cotton and corn states and only a small overlap between surveyed cotton and soybean growers. Hence, there is a relatively high correlation between the state dummy variables and the cotton grower dummy variable.

Ordered-Probit Results

Table 5 reports results for separate ordered-probit regression for each of the 10 BMPs. The dependent variable is the frequency of practicing a given BMP, where growers could choose between frequencies of never, rarely, sometimes, often, or always. Table 5 reports the effects of explanatory variables that were significant at the 5% and 10% levels. A positive sign (+) indicates an increase in the probability of practicing the BMP more frequently, while a negative minus sign (–) indicates the variable decreased the frequency of adopting the BMP.

Table 6 summarizes results of the ordered-probit regressions by explanatory variable. It reports the variables that had significant effects (at the 10% level) on adoption of each weed-resistance BMP. Results are summarized with and without state effects, with the data pooled across all growers.

In the count-data regressions, targeted cotton producers were more likely to adopt more BMPs often or always, but including state-specific effects attenuated this cotton-grower effect. This pattern repeats itself with frequency of adoption of individual BMPs. Targeted cotton producers appear to have a higher probability of more frequent adoption of a number of individual BMPs in the ordered probits. However, once we include state effects, the statistical significance of these relationships declines. In both ordered probits, soybean producers use multiple herbicides with different modes of action less frequently. In the count-data regression, a negative association existed between being a soybean producer and the number of BMPs adopted often or always, but the association was not significant.

The probit regressions also show that growers who expect yields higher than the county average are more likely to use multiple herbicides with different modes of action. In contrast, growers in counties with greater yield variability less frequently used herbicides with dif-

Table 5. Ordered-probit regressions for frequency of weed-resistance BMP adoption.

Explanatory variables	Scout before	Scout after	Clean field	Control early	Control escapes	Clean equipment	Use new seed	Different modes of action	Supplemental tillage	Follow label rate
Education		+[a]				–[b]		+[a]	–[b]	
Years farming				+[a]	–[b]			–[a]	–[a]	
Crop acres										
Percent land owned	+[b]		–[b]							
Roundup Ready acres							+[a]	–[b]		+[b]
Yield difference	+[b]	+[b]			+[a]		+[b]	+[a]		
Yield CV	–[b]	–[b]			–[a]			–[a]	–[a]	
Herfindahl index										
Custom application		–[b]	–[b]		–[a]					
Crop rep. dist. resistance				–[b]	–[a]					
County weed resistance								+[a]		
Resistance is a concern						–[a]	+[b]		–[a]	–[a]
Soybean								–[a]	–[a]	
Cotton	+[a]					+[b]				
Raises livestock		–[a]						+[b]		
AL									–[b]	
AR				+[a]					+[b]	
GA	–[b]			+[b]						
IL									+[a]	
IN					–[a]	+[a]	+[b]			
KS	+[a]	+[a]	+[a]			+[a]				
LA/MS				+[a]			–[b]			
MN			–[a]		–[a]	+[a]				+[a]
MO			+[b]				+[a]			
NE					–[a]	+[a]				+[b]
NC/SC/VA				+[a]						+[b]
ND					–[a]	+[a]				
OH					–[b]	+[b]				+[a]
SD			–[a]	+[a]		+[b]		–[a]		
TN			+[b]	+[a]						
TX/OK						+[a]	–[a]	–[b]	+[a]	
WI			–[b]					+[a]		
Likelihood P*	0.008	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.076

Adoption frequency categories: never, rarely, sometimes, often, always; + denotes variable had a positive and significant impact on frequency of adoption; – denotes variable had a negative and significant impact on frequency of adoption

[a] regression coefficient significant at 5% level; [b] coefficient significant at 10% level

** P-value of likelihood ratio test of null hypothesis that regression coefficients of all explanatory variables = 0*

ferent modes of action, practiced weed scouting, and

Table 6. Significant variables from ordered-probit regressions and their effect on the frequency of adopting weed resistance BMPs.

Explanatory variable	Ordered probit—No state effects		Ordered probit—State effects	
Soybean	Control early (–)	Diff. modes (–)	Diff. modes (–)	Suppl. tillage (–)
Cotton	Scout before (+)	Clean equip. (+)	Scout before (+)	Clean equip.(+)
	Scout after (+)	New Seed (–)		
	Suppl. tillage (+)			
Education	Scout after (+)		Scout after (+)	Clean equip. (–)
			Diff. modes (+)	Suppl. tillage (–)
Years farming	Control early (+)	Diff. modes (-)	Control early (+)	Diff. modes (–)
			Control esc. (–)	Suppl. tillage (–)
Crop acres	Scout before (+)			
% land owned	Scout before (+)		Scout before (+)	Clean field (–)
Roundup Ready acres	New Seed (+)	Label rate (+)	New Seed (+)	Label rate (+)
	Diff. modes (–)	Clean field (–)	Diff. modes (–)	
	Suppl. tillage (–)			
Yield difference	Control esc. (+)	Diff. modes (+)	Scout before (+)	New Seed (+)
			Scout after (+)	Diff. modes (+)
County yield CV	Scout after (–)	Control esc. (–)	Scout before (–)	Control esc. (–)
	Diff. modes (–)		Scout after (–)	Diff. modes (–)
			Suppl. tillage (–)	
Herfindahl index	Clean field (–)	Suppl. till. (+)		
Custom applications	Scout after (–)	Control esc. (–)	Clean field (–)	Control esc. (–)
Resistance in CRD	Control esc. (–)	Diff. modes (–)	Control early (–)	Control esc. (–)
Resistance in county	Diff. modes (+)		Diff. modes (+)	
Resistance a concern	Clean field (+)	Diff. modes (+)	Clean equip. (–)	Suppl. tillage (–)
	Clean equip.(–)	Suppl. till. (–)	New Seed (+)	Label rate (–)
	New Seed (+)			
Raised livestock	Scout after (–)		Scout after (–)	
	Diff. modes (+)			

controlled weed escapes. The positive impact of expected yield and the negative impact of yield variability are consistent with the count-data regressions.

A higher percentage of acreage planted to RR seed varieties was associated with greater use of new seed and less-frequent use of multiple herbicides with different modes of action. RR acreage was associated with more frequently following herbicide-label rates. Growers expressing a concern about resistance in the open-ended questions used supplemental tillage and cleaned equipment less frequently, but used new commercial seed more frequently. Growers operating in a county with reports of weed resistance more frequently used multiple herbicides with different modes of action.

Conclusions

Although cotton growers adopted BMPs somewhat more frequently, BMP adoption patterns were remarkably similar across crops. For all three crops, adoption rates of the same three BMPs were low. These were cleaning equipment, using multiple herbicides with different modes of action, and supplemental tillage. The other seven BMPs were practiced frequently (often or always) by all three grower types.

Generalized Poisson and negative binomial regression results suggest that factors significantly and positively associated with adopting more BMPs include (a) having more education; (b) having less experience (perhaps being younger?); (c) growing cotton; (d) expecting higher yields relative to the county average; and (e) farming in counties with a lower yield coefficient of

variation. In the ordered probits, farming in a county with a larger coefficient of variation of target crop yield *reduced* the probability of frequent adoption of several BMPs. Highly variable production outcomes may hinder the observability and trialability of BMPs (Pannell & Zilberman, 2001). With greater yield variability, it may be more difficult for growers to assess outcomes or benefits of BMP adoption. In contrast, the ratio of a grower's expected yield to the county average yield *increased* the probability of frequent adoption of BMPs. There may be some form of a "good manager" effect at work, where growers with higher yields (or at least higher expected yields) than their neighbors tend to adopt more BMPs more frequently. If BMPs increase current returns by minimizing percent yield loss to weeds, gains from damage reduction would be greater for growers with higher yields.

The survey data suggests that most growers are frequently adopting most BMPs. Extension efforts may thus be more effective by targeting a minority of growers (and a few practices). In particular, counties with a high coefficient of variation of crop yield would be areas to look for low BMP adoption.

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Selecting for Weed Resistance: Herbicide Rotation and Mixture

Hugh J. Beckie and Xavier Reboud*

Herbicide rotations and mixtures are widely recommended to manage herbicide resistance. However, little research has quantified how these practices actually affect the selection of herbicide resistance in weeds. A 4-yr experiment was conducted in western Canada from 2004 to 2007 to examine the impact of herbicide rotation and mixture in selecting for acetolactate synthase (ALS) inhibitor resistance in the annual broadleaf weed, field pennycress, co-occurring in wheat. Treatments consisted of the ALS-inhibitor herbicide, ethametsulfuron, applied in a mixture with bromoxynil/MCPA formulated herbicide (photosystem-II inhibitor/synthetic auxin), or in rotation with the non-ALS inhibitor at an ALS-inhibitor application frequency of 0, 25, 50, 75, and 100% (i.e., zero to four applications, respectively) over the 4-yr period. The field pennycress seed bank at the start of the experiment contained 5% ethametsulfuron-resistant seed. Although weed control was only marginally reduced, resistance frequency of progeny of survivors increased markedly after one ALS-inhibitor application. At the end of the experiment, the level of resistance in the seed bank was buffered by susceptible seed, increasing from 29% of recruited seedlings after one application to 85% after four applications of the ALS inhibitor. The level of resistance in the seed bank for the mixture treatment after 4 yr remained similar to that of the nontreated (weedy) control or 0% ALS-inhibitor rotation frequency treatment. The results of this study demonstrate how rapidly ALS-inhibitor resistance can evolve as a consequence of repeated application of herbicides with this site of action, and supports epidemiological information from farmer questionnaire surveys and modeling simulations that mixtures are more effective than rotations in mitigating resistance evolution through herbicide selection.
Nomenclature: Bromoxynil; ethametsulfuron; MCPA; field pennycress, *Thlaspi arvense* L. THLAR; wheat, *Triticum aestivum* L. 'AC Barrie'.
Key words: ALS inhibitor, herbicide resistance, resistance management, seed bank, selection pressure.

Herbicide rotation can be defined as the application of herbicides of different sites of action (i.e., groups) to multiple crops over multiple growing seasons in a field (Beckie 2006). The level of adoption of herbicide rotation for weed resistance management has increased markedly over the past decade in the prairies of western Canada (provinces of Alberta, Saskatchewan, and Manitoba). In 1998, fewer than 50% of farmers practiced herbicide rotation, even though awareness was high (Beckie et al. 1999). By 2003, 70 to 90% of farmers in Saskatchewan and Manitoba, respectively, claimed to rotate herbicides by site of action (Beckie 2007). It is the most common herbicide resistance management practice cited by farmers in survey questionnaires conducted in Canada (Beckie 2007) and Australia (Shaner et al. 1999). At present, over half of the herbicide products sold in Canada have resistance management labeling, which includes group identification symbols on the label and guidelines for resistance management practices in the use directions (M. Downs, PMRA, personal communication). This labeling regulation in Canada, which was first implemented in 1999, probably facilitated the adoption of herbicide rotation. However, the lack of suitable herbicide options associated with crop rotation can be a substantial deterrent to herbicide rotation (Bourgeois et al. 1997; Légère et al. 2000).

Acceptance by farmers of herbicide mixtures for proactive resistance management of broadleaf weeds has been aided by cost-incentive programs from industry, formulated mixtures (e.g., phenoxy plus an ALS inhibitor), and the rapid evolution of resistance in specific cases. A survey of 1,800 farmers in the Canadian prairies from 2001 to 2003 indicated that a majority of them intentionally or inadvertently tank-mix herbicides to delay or manage ALS-inhibitor–resistant broadleaf weeds (Beckie et al. 2008b). For farmers dealing with ALS-inhibitor resistance, the ALS-inhibitor partner may provide relatively broad-spectrum weed control while the non-ALS-inhibitor partner controls the resistant broadleaf weed. However, if mixing partners of different sites of action do not meet the criteria of similar efficacy and persistence, plus different propensity for selecting for resistance in target species, the effectiveness of mixtures for delaying target-site resistance will be reduced. Mixtures may inadvertently accelerate the evolution of multiple resistances if they fail to meet basic criteria for resistance management and are applied repeatedly (Rubin 1991). Moreover, mixtures to prevent or delay metabolic resistance in grass weeds, where this mechanism is most prevalent, may be cost-prohibitive unless the mixed graminicides interact synergistically and can be applied at lower rates. Obstacles to farmer adoption of mixtures for herbicide resistance management include increased cost and availability of suitable mixing partners that meet the criteria outlined above.

Herbicide rotations or mixtures generally have the greatest effect in delaying resistance when the mechanism conferring resistance is target site–based, the target weed species are highly self-pollinated, and seed spread is restricted (Beckie et al. 2001). Based on a compounded resistance frequency model, the probability of herbicide-resistant mutants with multiple mechanisms of resistance (target site–based) in an unselected population is the product of the probabilities of

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resistance to each affected herbicide site of action and thus is relatively rare (Wrubel and Gressel 1994). Herbicide mixtures, whose components are equally effective against the target weed species, are predicted through model simulations to delay resistance longer than rotations (Diggle et al. 2003; Powles et al. 1997).

Evolution of herbicide resistance is often attributed to a lack of herbicide rotations or mixtures; i.e., frequent or repeated use of herbicides of the same site of action. Nevertheless, there is epidemiological or anecdotal evidence for the utility of herbicide rotations and mixtures in delaying the evolution of target-site resistance (Beckie 2006). However, little research has quantified how these practices impact herbicide resistance selection in weeds. Only one long-term experiment has examined the effect of frequency of herbicide use on the evolution of resistance. In a large-plot experiment conducted in western Canada from 1979 to 1998, resistance in wild oat (*Avena fatua* L.) to triallate occurred after 18 yr, where the herbicide was applied annually in continuous spring wheat, but not where it was applied 10 times in the wheat phase of a wheat-fallow rotation over the same period (Beckie and Jana 2000).

In this paper, we describe the results of a 4-yr field experiment conducted at two sites in Saskatchewan that examined the impact of herbicide rotation and mixture in selecting for ALS-inhibitor resistance in a broadleaf weed species. The model species chosen was field pennycress (referred to as stinkweed in Canada). Field pennycress is a diploid ($2n = 14$), self-compatible, and readily autogamous (ca. 3% outcrossing; Hume 1990) annual weed that is a member of the Brassicaceae family (reviewed in Best and McIntyre 1975; Warwick et al. 2002). The species has a persistent seed bank of 10 to 20 yr (Van Acker 2009), high fecundity, and the growth habit of a winter or summer annual. Native to Eurasia, this crucifer is widely introduced and naturalized in temperate regions around the world. The species occurs in all the Canadian provinces and territories, and is an economically important weed of field crops in the Canadian prairies. Farmers spend almost $200 million annually to control this weed (J. Leeson, unpublished data). In weed surveys of annual crops in the early 2000s across the prairies, field pennycress ranked seventh in relative abundance (Leeson et al. 2005). Resistance to ALS-inhibitor herbicides in this species was first reported globally in two populations from Alberta in 2000 (Beckie et al. 2007).

Materials and Methods

Sites. The experiment was conducted from 2004 to 2007 at two sites in Saskatchewan, near Watrous and North Battleford. The Watrous site is located in the subhumid Aspen Parkland ecoregion (defined by climate, natural vegetation, and soils) at 51.4° N, 108.6° W; the North Battleford site is located in the subhumid Boreal Transition ecoregion at 52.0° N, 105.2° W. The sites were located on permanent pastureland owned by the Prairie Farm Rehabilitation Administration of Agriculture and Agri-Food Canada. Because herbicide-resistant weed seed was used in the experiment, a large isolation buffer between adjacent cropland was desired. A 1-ha fenced area at each site had been cropped annually since 1997. Observations of field pennycress recruitment from 1997 to 2003 confirmed the absence of a seed bank at each site. The soil at the Watrous site is an Oxbow sandy loam (Udic Haploboroll) with 4.0% organic matter (OM) and pH 7.3; soil at the North Battleford site is a Meeting Lake loam (Boralfic Haploboroll) with 2.5% OM and pH 7.0. All soils were nonsaline. Precipitation and air temperature during the growing season (May to August) were recorded at weather stations nearest to the two sites (26 to 42-km distance).

Experimental Design and Protocol. The experiment was arranged in a randomized complete block design with four replications. Plot dimensions were 4 by 10 m. Treatments consisted of the ALS inhibitor (group-2 herbicide; Mallory-Smith and Retzinger 2003), ethametsulfuron, applied in rotation with a bromoxynil/MCPA formulated herbicide ([280 g/L bromoxynil, a photosystem-II inhibitor] / [280 g/L MCPA ester, a synthetic auxin]) at an ALS-inhibitor rotation frequency of 0, 25, 50, 75, and 100% (i.e., zero to four applications, respectively) over the 4-yr period (Table 1). Both herbicides generally have short soil residual activity under western Canadian climatic conditions (Saskatchewan Ministry of Agriculture 2008). However, the soil persistence and activity of ethametsulfuron, a sulfonylurea herbicide, depends upon soil OM and pH. Each phase of the herbicide rotation was present each year. Thus, the 25% ALS-inhibitor rotation frequency was represented by four treatments: ethametsulfuron applied in yr 1, 2, 3, or 4 ("on" years) with bromoxynil/MCPA applied in the "off" years (Table 1). The 50% ALS-inhibitor rotation frequency was represented by six treatments: ethametsulfuron applied in yr 1 and 2; 1 and 3; 1 and 4; 2 and 3; 2 and 4; and 3 and 4. The 75% ALS-inhibitor rotation frequency was represented by four treatments: ethametsulfuron applied in yr 1, 2, and 3; 1, 2, and 4; 2, 3, and 4; and 1, 3, and 4. The sole mixture treatment was ethametsulfuron plus bromoxynil/MCPA applied each year (Table 1). Additionally, a nontreated (weedy) control and a weed-free control treatment were included.

Herbicides were applied using a hand-held boom equipped with flat fan nozzle tips[1] that delivered a spray volume of 110 L/ha at 275 kPa when the majority of weed seedlings were in the two- to three-leaf stage. Commercial formulations of the herbicides were applied at recommended rates (Saskatchewan Ministry of Agriculture 2008). Ethametsulfuron was applied at 22 g ai/ha, and the bromoxynil/MCPA formulated herbicide at 550 g ai/ha. A nonionic surfactant[2] was added to the ethametsulfuron spray solution at 0.25% (v/v). Sparse populations of other broadleaf weeds were controlled by roguing as required. Wild oat was controlled in all plots by fall-applied granular triallate.

Hard red spring wheat ('AC Barrie') was seeded using a disc drill with 20-cm row spacing in early to mid-May, depending on soil moisture and temperature conditions. The crop was seeded parallel to the short dimension of plots at 80 kg/ha at a 2.5 to 5-cm depth, depending on soil moisture conditions. Fertilizer nitrogen (N), phosphorus (P), and sulphur (S) were seed-placed or side-banded at rates based on soil test recommendations. Plots were tilled (8 to 10 cm deep)

Table 1. Experiment treatments: Acetolactate synthase (ALS) inhibitor (ethametsulfuron) in rotation or mixture with bromoxynil/MCPA.[a]

1	Nontreated (weedy) control
2	Weed-free control
ALS-inhibitor rotation treatments:	
3	0% frequency—no ALS inhibitor (bromoxynil/MCPA applied each year)
4	25% frequency—ALS inhibitor in yr 1 (bromoxynil/MCPA yr 2, 3, 4)
5	25% frequency—ALS inhibitor in yr 2 (bromoxynil/MCPA yr 1, 3, 4)
6	25% frequency—ALS inhibitor in yr 3 (bromoxynil/MCPA yr 1, 2, 4)
7	25% frequency—ALS inhibitor in yr 4 (bromoxynil/MCPA yr 1, 2, 3)
8	50% frequency—ALS inhibitor in yr 1, 2 (bromoxynil/MCPA yr 3, 4)
9	50% frequency—ALS inhibitor in yr 1, 3 (bromoxynil/MCPA yr 2, 4)
10	50% frequency—ALS inhibitor in yr 1, 4 (bromoxynil/MCPA yr 2, 3)
11	50% frequency—ALS inhibitor in yr 2, 3 (bromoxynil/MCPA yr 1, 4)
12	50% frequency—ALS inhibitor in yr 2, 4 (bromoxynil/MCPA yr 1, 3)
13	50% frequency—ALS inhibitor in yr 3, 4 (bromoxynil/MCPA yr 1, 2)
14	75% frequency—ALS inhibitor in yr 1, 2, 3 (bromoxynil/MCPA yr 4)
15	75% frequency—ALS inhibitor in yr 1, 2, 4 (bromoxynil/MCPA yr 3)
16	75% frequency—ALS inhibitor in yr 2, 3, 4 (bromoxynil/MCPA yr 1)
17	75% frequency—ALS inhibitor in yr 1, 3, 4 (bromoxynil/MCPA yr 2)
18	100% frequency—ALS inhibitor applied each year (no bromoxynil/MCPA)
Mixture treatment:	
19	ALS inhibitor + bromoxynil/MCPA each year
Orthogonal contrasts:	
Treatment 3 vs. 19 (all measured variables)	
Treatments 4–7 (averaged) vs. 19 (all measured variables)	
Treatment 1 vs. 3; 1 vs. 19 (% resistant seeds or seedlings in the seed bank)	

[a] Ethametsulfuron applied at 22 g ai/ha (plus nonionic surfactant at 0.25% v/v); bromoxynil/MCPA formulated herbicide applied at 550 g ai/ha.

length-wise once immediately prior to seeding using a field cultivator with mounted harrows.

The field pennycress seed bank at both sites was established in 2003, the year prior to initiation of the experiment. In late autumn near freeze-up, a ratio of 5 ethametsulfuron-resistant seed : 95 susceptible seed mixture of field pennycress was drilled into the soil at a 2.5-cm maximum depth in the long direction of plots (except for the weed-free control treatment) at a rate of 75 germinable seeds/m^2. The susceptible population originated from central Saskatchewan and was confirmed to contain no resistant individuals; the resistant population, CAB, originated from central Alberta. Seeds from both populations exhibited little dormancy; the germination rate for the seed lots consistently exceeded 95%. The resistant biotype has been well characterized (Beckie et al. 2007). The biotype is highly resistant to ethametsulfuron, exhibits a low level of resistance to metsulfuron and imazethapyr, but is not resistant to florasulam, a triazolopyrimidine ALS inhibitor. Resistance in the CAB population was attributed to a Pro_{197} Leu mutation, conferred by a single, dominant gene.

Data Collection. Crop and weed plant density were measured 3 wk after emergence in four randomly placed 0.25-m^2 quadrats per plot. At 3 wk after herbicide application, weed seedling density was enumerated using the same procedure. Field pennycress aboveground biomass was harvested at maturity. Shoot biomass from each of the four quadrats from each plot was collected in a cotton bag and subsequently dried in a forced-air drying room. Thereafter, plants were threshed and seeds were weighed and counted. Seeds were subsequently stored at ambient room temperature. Wheat grain yield was determined at crop maturity by harvesting aboveground biomass in two 1-m^2 quadrats per plot using procedures similar to those used for the weed harvest. Grain weight was adjusted to 10% moisture content. The crop that remained in each plot was harvested using a small-plot combine, ensuring that residue was contained within the plot area.

Each year in early spring after the preceding harvest, field pennycress seeds from each plot were tested in the greenhouse for resistance to ethametsulfuron. A total of 150 seeds from each sample (one aggregate sample per plot) were screened. Twenty-five seeds were planted in a potting mixture of soil, peat, vermiculite, and sand (3 : 2 : 2 : 2 by volume) plus a slow-release fertilizer (150 g of 26–13–0 per 75 L potting mixture) in trays (each tray considered a replicate) measuring 52 by 26 by 5 cm. Environmental conditions were a 20/16 C day/night temperature regime with a 16-h photoperiod supplemented with 230 $\mu mol/(m^2 \cdot s)$ illumination. Flats were watered daily to field capacity. Seedlings were treated with ethametsulfuron at the two-leaf stage. The herbicide was applied using a moving-nozzle cabinet sprayer equipped with a flat-fan nozzle tip[1] calibrated to deliver 200 L/ha of spray solution at 210 kPa in a single pass over the foliage. A nonionic surfactant[2] was added at 0.25% (v/v). Treatments (and nontreated controls) were replicated three times in this completely randomized experiment and the tests were repeated. In early spring each year, any seeds not tested for resistance were returned to plots in areas where they had been harvested the previous year.

In mid-April of 2008, the year after the experiment was terminated, soil was sampled to determine the viable fraction of the seed bank and percentage of seeds resistant to ethametsulfuron. Twenty-five 5-cm-diam by 10-cm-deep soil cores, sampled in a "W" pattern, were collected from each plot. Cores from each plot were combined and the bulk samples were frozen until late spring/summer of 2008, when four growth periods were conducted in the greenhouse in trays measuring 52 by 26 by 5 cm. Soil in trays was watered twice

daily. A liquid N–P–S fertilizer was applied to each tray once during each of the four growth periods. Field pennycress seedlings were counted and then sprayed by the four-leaf stage with ethametsulfuron at 22 g ai/ha using the procedures described previously. Three wk after spraying, survivors were counted, removed, and the soil was remixed. The sample was returned to the freezer for 3 wk in advance of the second growth period. This procedure was repeated for the third and fourth growth periods.

Data Analyses. Data were logarithmically or square-root transformed prior to ANOVA. Data were subjected to a combined ANOVA using the Proc MIXED procedure in SAS software (SAS 1999). Replicate, site, and year were considered random effects, and herbicide treatment as a fixed effect. Weed response to treatments (seedling density, aboveground biomass, seed production, percentage of seeds produced annually resistant to ethametsulfuron, percentage of viable seeds in the seed bank at the end of the experiment resistant to ethametsulfuron) was analyzed using curvilinear regression. Data were averaged across phases for the 25, 50, or 75% ALS-inhibitor rotation frequencies. Weed responses to ALS-inhibitor rotation frequency were best described by the quadratic (2nd-order polynomial) or exponential models. Regression analyses were performed on treatment means averaged over replications as recommended by Gomez and Gomez (1984). Coefficients of determination (R^2) were calculated as described by Kvalseth (1985) using the residual sum of squares value from the SAS output. Standard errors of the parameter estimates were calculated. Planned orthogonal contrasts (listed in Table 1) were performed to compare specific treatment means when significant treatment effects from ANOVA were indicated ($P \leq 0.05$) (Bertram and Pedersen 2004).

Results and Discussion

Weather Conditions. Total growing season precipitation was above normal for two site-years, and near-normal for six site-years (data not shown). At the time of crop establishment in May, less than 80% of the normal (30-yr mean) monthly precipitation was received for three of the eight site-years. Average growing season temperatures were near normal for all site-years.

Wheat Stand Establishment and Grain Yield. Satisfactory crop plant densities were realized in all years at both sites. Wheat seedling density at 3 wk after emergence ranged from 136 ± 3 (SE) plants/m^2 in 2007 to 241 ± 6 plants/m^2 in 2004. Relatively low stand densities in 2007 were caused by dry soil conditions at planting. Combined ANOVA results indicated no significant effect ($P > 0.05$) of herbicide treatment on wheat grain yield (data not shown). Wheat yield loss by field pennycress interference can vary widely, depending on plant densities and relative time of emergence (Warwick et al. 2002). Based on yield loss equations derived from data from a 10-yr study in Saskatchewan from 1981 to 1990, field pennycress at a density of 52 plants/m^2 would be expected to result in only a 3% grain yield loss in spring wheat (Hume 1993). In the spring of 2004 (first year of the experiment) immediately prior to herbicide treatment, field pennycress seedling densities across all plots at the two sites averaged 48.7 ± 2.1 plants/m^2.

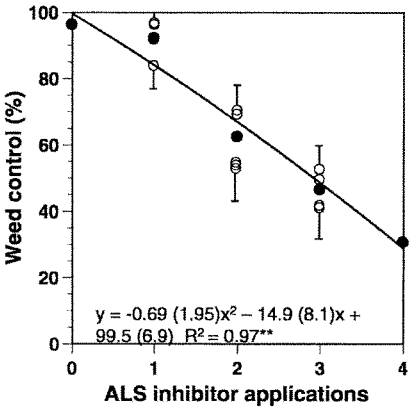


Figure 1. Response of field pennycress seedling density ('●' denotes means, '○' denotes phases of an herbicide rotation; maximum low and high weed control SE bars shown) to ethametsulfuron, an acetolactate synthase (ALS) inhibitor, applied one (25% frequency), two (50% frequency), three (75% frequency), or four (100% frequency) times during the 4-yr experiment (quadratic regression equation with SE in brackets: $y = ax^2 + bx + c$ where a = the curvilinear coefficient, b = the linear coefficient, c = the intercept, y = the dependent variable, and x = the number of ALS-inhibitor applications; R^2 is significant (**) at $P < 0.01$).

Weed Seedling Density-Weed Control. The decline in field pennycress control in wheat was curvilinear with increasing number of ALS-inhibitor applications (Figure 1). Weed control over 4 yr averaged 96% in plots treated annually with bromoxynil/MCPA (0% ALS-inhibitor rotation frequency). Similarly, weed control over 4 yr averaged 97% in the herbicide mixture (ethametsulfuron + bromoxynil/MCPA) treatment (nonsignificant contrast, $P > 0.05$) (Table 2). Field pennycress is normally highly sensitive to ethametsulfuron or bromoxynil/MCPA. After one application of ethametsulfuron (in yr 1, 2, 3, or 4), weed control declined slightly (mean of 92%). Nonetheless, this level of control was less than that of the mixture treatment (significant contrast, $P \leq 0.05$). Maximum low and high weed control SE bars shown in Figure 1 indicate the variability in weed control among the phases of a given ALS-inhibitor rotation frequency.

Field pennycress seedling density was only suppressed (i.e., < 80% efficacy) by two or more ALS-inhibitor applications. After two applications of ethametsulfuron (in yr 2, 3, or 4), weed control had declined to 62%; after three applications of the ALS inhibitor (yr 3 or 4), weed control averaged 46%, declining to 31% after four consecutive annual ALS-inhibitor applications. Therefore, starting with a weed population comprising 5% ALS-inhibitor–resistant individuals, weed

Table 2. Field pennycress response averaged over 4 yr of the experiment (seed bank after 4 yr) for the 0 and 25% acetolactate synthase (ALS) inhibitor (ethametsulfuron) rotation frequency treatments and mixture (ALS inhibitor plus bromoxynil/MCPA) treatment.

	Seedling density	Biomass at maturity	Seed production	Resistant seed[a]	Resistant seed bank[a]
	% control	g/m^2	number/m^2	%	%
0% ALS-inhibitor frequency (treatment 3, Table 1)	96	0.3	155	2	4
25% ALS-inhibitor frequency (treatments 4–7 averaged, Table 1)	92	11.0	1210	59	29
Mixture (treatment 19, Table 1)	97	0.6	178	3	8
Contrast[b]: 0% ALS inhibitor *vs.* mixture	NS	NS	NS	NS	NS
Contrast: 25% ALS inhibitor *vs.* mixture	*	*	*	*	*

[a] The percentage of seeds resistant to ethametsulfuron in the nontreated control was 5% when averaged over 4 yr (annual seed production) and in the seed bank at the end of the experiment—not significantly different ($P > 0.05$) from the 0% ALS-inhibitor rotation frequency treatment or mixture treatment.

[b] *, significant at $P \leq 0.05$; NS, nonsignificant.

control would not noticeably decline after one application of an ALS inhibitor, but would be unacceptable (i.e., < 80% efficacy) after only two applications.

Weed Biomass and Seed Production. Both field pennycress biomass at maturity and seed production responded similarly as seedling density to increasing number of ALS-inhibitor applications (Figures 2 and 3). Responses were best described by the quadratic function. The greatest variation in biomass and seed return responses among phases, similar to that of weed seedling density, was observed in plots with the 50% (two-application) ALS-inhibitor rotation frequency. After four ALS-inhibitor applications, field pennycress plant biomass exceeded 100 g/m^2 (i.e., 1,000 kg or 1.0 tonne/ha). Whereas 155 seeds/m^2 were produced in plots with the 0% ALS-inhibitor rotation frequency, 1,210, 5,770, 16,600, and 25,700 seeds/m^2 were produced where ethametsulfuron was applied one (25%), two (50%), three (75%), and four times (100%), respectively.

In field studies in Saskatchewan, Hume (1993) found that spring-emerging field pennycress in wheat produced about 14,000 seeds per plant. Given its persistent seed bank, field pennycress control by herbicides and crop competition is essential to minimize seed production, a basic tenant of herbicide-resistance management. Four-yr means of weed biomass (0.6 g/m^2) and seed production (178 seeds/m^2) responses for the herbicide mixture treatment were similar to those for the 0% ALS-inhibitor rotation frequency treatment (nonsignificant contrasts, $P > 0.05$), indicating control of both resistant and susceptible field pennycress by bromoxynil/MCPA. However, means for both plant variables were significantly different between the 25% ALS-inhibitor rotation frequency and the mixture treatment (Table 2).

Percentage Resistant Seeds. Greater than 95% of seeds tested were viable (data not shown). In contrast to weed density, biomass, and seed production, the percentage of seeds resistant to ethametsulfuron as a function of its application frequency was best described by an exponential (reciprocal) model (Figure 4). The resistance percentage increased rapidly from 2% (0% ALS-inhibitor rotation frequency) to nearly 60% after only one ALS-inhibitor application (25% rotation frequency). After two applications, the resistance percentage had increased to 92%, but changed little with one or two additional applications over the 4-yr period. For the mixture treatment, the percentage of seed resistant to the ALS inhibitor averaged 3%, similar to that of the 0% ALS-inhibitor rotation frequency treatment (nonsignificant contrast, $P > 0.05$). In the nontreated control treatment, a 4-yr mean of 5% resistance was measured, unchanged from the resistance frequency established at the beginning of the experiment.

The rapid increase in resistance frequency of progeny of surviving plants after only one ALS-inhibitor application helps explain the frequent observations by farmers of good weed control in one year but failure the next, when using the same herbicide or product with the same site of action. Weed

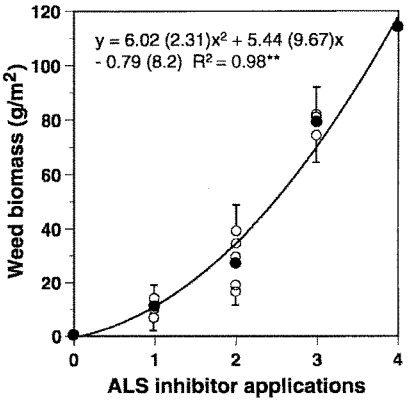


Figure 2. Response of field pennycress biomass at maturity ('●' denotes means, '○' denotes phases of an herbicide rotation; maximum low and high biomass SE bars shown) to ethametsulfuron, an acetolactate synthase (ALS) inhibitor, applied one (25% frequency), two (50% frequency), three (75% frequency), or four (100% frequency) times during the 4-yr experiment (quadratic regression equation with SE in brackets: $y = ax^2 + bx + c$ where a = the curvilinear coefficient, b = the linear coefficient, c = the intercept, y = the dependent variable, and x = the number of ALS-inhibitor applications; R^2 is significant (**) at $P < 0.01$).

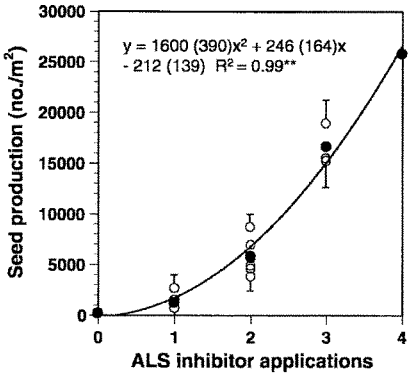


Figure 3. Response of field pennycress seed production ('●' denotes means, '○' denotes phases of an herbicide rotation; maximum low and high seed production SE bars shown) to ethametsulfuron, an acetolactate synthase (ALS) inhibitor, applied one (25% frequency), two (50% frequency), three (75% frequency), or four (100% frequency) times during the 4-yr experiment (quadratic regression equation with SE in brackets: $y = ax^2 + bx + c$ where a = the curvilinear coefficient, b = the linear coefficient, c = the intercept, y = the dependent variable, and x = the number of ALS-inhibitor applications; R^2 is significant (**) at $P < 0.01$).

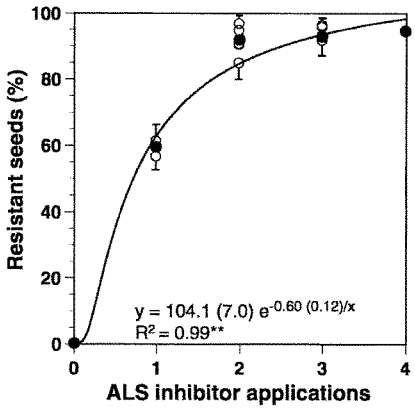


Figure 4. Response of percentage resistance of field pennycress seeds ('●' denotes means, '○' denotes phases of an herbicide rotation; maximum low and high resistant seed percentage SE bars shown) to ethametsulfuron, an acetolactate synthase (ALS) inhibitor, applied one (25% frequency), two (50% frequency), three (75% frequency), or four (100% frequency) times during the 4-yr experiment (exponential reciprocal regression equation with SE in brackets: $y = ce^{-bx}$, where c = the intercept, bc = the initial slope, y = the dependent variable, and x = the number of ALS-inhibitor applications; R^2 is significant (**) at $P < 0.01$).

populations in a field undergoing herbicide resistance selection are typically a mixture of homozygous and heterozygous individuals, with resistance alleles segregating from one generation to the next. The high selection pressure exerted by ethametsulfuron on this mixed resistant/susceptible field pennycress population, with resistant individuals possessing target-site mutation conferred by a single nuclear gene with a high degree of dominance, are ideal conditions for the rapid enrichment of resistance alleles with increasing number of ALS-inhibitor applications.

Percentage Resistant Seedlings in the Seed Bank. The buffering of enrichment of ALS-inhibitor resistance by susceptible seed in the seed bank was apparent at the end of the experiment (Figure 5). The level of resistance in the seed bank in plots with 0% ALS-inhibitor rotation frequency was 4%; this level of resistance rose to 29% after one application, 54% after two applications, 71% after three applications, and 85% after four applications of ethametsulfuron. In the mixture treatment, the level of resistance was 8%; however, orthogonal contrast indicated no significant difference ($P > 0.05$) from either the nontreated control (5%) or the 0% ALS-inhibitor rotation frequency treatment (Table 2). The percentage of recruited seedlings resistant to ethametsulfuron was greater in plots treated with 25% ALS-inhibitor rotation frequency than that of the mixture treatment (Table 2).

The similar resistance frequency in the seed bank of the nontreated control (5%), or the 0% ALS-inhibitor rotation frequency (4%), as that of the initial seed bank established in 2003 suggests little fitness difference between these resistant and susceptible field pennycress populations in the absence of selection pressure. The similar percentage resistance in the seed bank for the 0% ALS-inhibitor rotation frequency and mixture treatments relative to that of the nontreated control indicates essentially zero selection pressure (i.e., resistant and susceptible genotypes controlled equally). Thus, little decline would be expected in the proportion of resistant to susceptible individuals in a field over time after use of the ALS inhibitor was discontinued.

The relatively slow evolution of ALS-inhibitor resistance in field pennycress populations in western Canada is partially due to the longevity of seeds (10–20 yr) in the seed bank. Nevertheless, after four ALS-inhibitor applications, over 80% of seedlings recruited from the seed bank were resistant. For weed species such as kochia [*Kochia scoparia* (L.) Schrad.] with a short-lived seed bank (1–2 yr; Friesen et al. 2009), the seed bank resistance response would probably be depicted by a steeper curve than that observed in this experiment. Similarly, less buffering of resistance evolution by the seed bank would occur under a low soil disturbance no-tillage environment (Beckie et al. 2008b). In the minimum tillage regime used in this study—i.e., one spring tillage operation—partial weed seed burial to tillage depth would favor seed dormancy and persistence (Warwick et al. 2002).

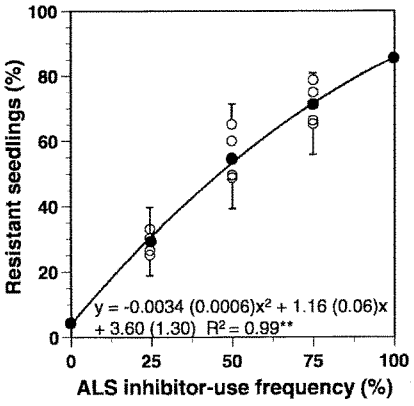


Figure 5. Response of percentage resistant field pennycress seedlings ('●' denotes means, '○' denotes phases of an herbicide rotation; maximum low and high resistant seedling percentage SE bars shown) recruited from the seed bank to ethametsulfuron, an acetolactate synthase (ALS) inhibitor, applied one (25% frequency), two (50% frequency), three (75% frequency), or four (100% frequency) times during the 4-yr experiment (quadratic regression equation with SE in brackets: $y = ax^2 + bx + c$ where a = the curvilinear coefficient, b = the linear coefficient, c = the intercept, y = the dependent variable, and x = the number of ALS-inhibitor applications; R^2 is significant (**) at $P < 0.01$).

The results of this study dramatically illustrate how rapidly ALS-inhibitor resistance can evolve in sensitive weed species with repeated ALS-inhibitor applications. The most relevant data of this study is arguably that of the seed bank resistance enrichment as impacted by herbicide rotation and mixture. The enrichment of resistant alleles is roughly proportional to the number of ALS-inhibitor applications, although a decline in the rate of increase in the level of resistance was apparent after three applications (Figure 5). In the Canadian prairies, the high relative abundance and long persistence of field pennycress in the seed bank favors the existence of a mixed population with some susceptible individuals, even under intense ALS-inhibitor selection pressure. Moreover, some unsprayed seedlings (e.g., spray misses or near water bodies) or those receiving a sub-lethal herbicide dose due to a myriad of factors affecting retention and absorption will survive, reproduce, and thus maintain susceptible genotypes in seed banks, even under high ALS-inhibitor selection pressure.

Because ALS-inhibitor resistance can evolve in field weed populations after fewer than five applications (Beckie 2006), herbicide rotation as a tactic to delay such resistance is probably short-term at best. Based on modeling simulations and results presented herein, a mixture of an ALS inhibitor with a photosystem-II inhibitor (site B, group 6; Mallory-Smith and Retzinger 2003) or auxinic herbicide (group 4) or both is a much more effective tactic than rotation to delay ALS-inhibitor resistance. The unregistered mixture of ethametsulfuron and bromoxynil/MCPA meet the criteria for effective proactive resistance management of field pennycress. If a farmer plans to use an ALS-inhibitor herbicide for broadleaf weed control, we recommend it be tank-mixed with a suitable partner whenever possible to slow the steadily increasing number of cases of ALS-inhibitor resistance in broadleaf weeds in the prairies.

Although small-plot studies are inadequate in assessing the risk of multiple resistance in weeds as a result of repeated use of the same mixture, the rarity of ALS inhibitor plus auxinic or photosystem-II inhibitor multiple resistance in broadleaf weed species in the Canadian prairies (only one case documented in 1996 by Hall et al. 1998) is compelling evidence that alleles resistant to these non-ALS inhibitors introduced over 50 yr ago are present at extremely low frequencies in populations. Indeed, there are few cases of weed resistance in western Canada to synthetic auxins or photosystem-II inhibitors, despite their intensive and widespread use (Beckie et al. 2008a) since the beginning of the agrichemical era. An unusually low rate of mutation of the locus conferring resistance, or alternatively few fit mutations, are speculated to contribute to the slow evolution of resistance to phenoxy and some other low-risk herbicides (Jasieniuk et al. 1996).

The wide disparity in rate of herbicide resistance evolution to ALS inhibitors vs. phenoxy herbicides or photosystem-II inhibitors is best exemplified in kochia. ALS-inhibitor resistance in this species was first documented in the prairies in 1988, 5 yr after introduction of herbicides with this site of action (Friesen et al. 2009). Twenty yr later, about 90% of populations in the Canadian prairies exhibit some level of ALS-inhibitor resistance (Beckie 2009), whereas resistance in this species to non-ALS inhibitors has not been reported. There are few alternative herbicide options to control ALS-inhibitor–resistant kochia in annual legume crops, such as field pea (*Pisum sativum* L.) and lentil (*Lens culinaris* L.) grown on over 2 million ha in Canada in 2008 (Statistics Canada 2008). In these and other crops such as mustard (*Brassica juncea* L. or *Sinapis alba* L.), farmers rely on ALS-inhibitor herbicides to control broadleaf weeds. Although too late for kochia, we believe utilization of herbicide mixtures for proactive resistance management of other broadleaf weeds with a propensity for ALS-inhibitor resistance evolution will be more cost-effective and sustainable in the long-term than ALS-inhibitor herbicides applied in rotation. The challenge for industry is finding suitable non-ALS-inhibitor partners with selectivity in our major dicot crops.

Sources of Materials

[1] TeeJet 8002VS nozzle tip, Spraying Systems Co., North Avenue at Schmale Road, P.O. Box 7900, Wheaton, IL 60189-7900.

[2] Agral 90® surfactant, Norac Concepts Inc., P.O. Box 62023, Ottawa, ON I1C 7H8.

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Herbicides used in combination can reduce the probability of herbicide resistance in finite weed populations

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Summary

A simulation study was conducted to examine the effect of pattern of herbicide use on development of resistance to two herbicides with different modes of action in finite weed populations. The effects of the size of the treatment area (analogous to initial weed population), germination fraction and degree of self-pollination in the weed were investigated. The results indicate that the probability of developing resistance to one or both herbicides decreases as the size of the area/initial population decreases. For treatment areas of 100 ha or less with an initial weed seedbank of 100 seeds m^{-2} and initial frequencies of the resistance genes of 10^{-6}, development of resistance to both herbicides (double-resistance) is uncommon within 50 years for all types of weeds if both herbicides are used in all years (used in combination). If herbicides are used in alternate years (rotated) double-resistance almost always occurs in 100 ha areas but is uncommon in areas of 1 ha or less. The results suggest that adoption of practices that limit movement of weeds in conjunction with using herbicides in combination rather than in rotation can substantially delay development of herbicide resistance.

Keywords: simulation, modelling, mixtures, reduction, herbicide resistance.

Introduction

The development of herbicide resistance in weed populations under herbicide selection is an evolutionary phenomenon. Herbicides are very intense selective agents and where genetic variability for herbicide response exists in weed populations, evolution of herbicide resistance can be rapid. The probability and rate of herbicide resistance evolution depends on the interplay between the population dynamics and population genetics of weed populations (Maxwell & Mortimer, 1994; Jasieniuk *et al.*, 1996; Diggle & Neve, 2001). Important evolutionary factors include the intensity of selection (degree of discrimination between genotypes); the frequency of resistance traits in natural (unselected) populations; the mode of inheritance of resistance; the relative fitness of susceptible and resistant biotypes in the presence and absence of herbicide; and gene flow within and between populations. The intrinsic population dynamics of weed populations is also important, especially in the area of seedbank dynamics where it is recognized that a persistent seedbank can act as a buffer to evolution (Mortimer *et al.*, 1993).

Several simulation models of the population genetics and dynamics of herbicide resistance in weed populations have been developed (Gressel & Segel, 1978; Maxwell *et al.*, 1990; Gardner *et al.*, 1998; Cavan *et al.*, 2000). These models differ in their approaches, particularly in relation to population genetics, and the applications and limitations of the various methodologies have been discussed by Diggle and Neve (2001). In particular, the authors draw attention to the benefits of explicitly accounting for each genotype in the population. The common alternative approach of assuming Hardy–Weinberg equilibrium between successive generations may lead to erroneous conclusions about resistance

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evolution under conditions that violate the assumption of random mating. Such conditions are common and include incomplete germination, immigration and emigration of seed and pollen (gene flow); staggered flowering time; and any bias towards self-pollination. These factors affect the rate of evolution of herbicide resistance because they determine the frequency of the haplotypes that are involved in mating at any given time.

Where more than one resistance gene is being considered, an assumption of genotypic equilibrium between successive generations is inappropriate, even under conditions of completely random mating. While individual genes reach equilibrium in each generation, equilibrium combinations of genes are only achieved after many generations of random mating. For this reason, simulation of the dynamics of more than one gene in a population requires explicit accounting of each genotype. The evolution of herbicide resistance in the field typically involves simultaneous selection by herbicides with more than one mode of action. Consequently, consideration of two (or more) genes is of practical significance.

Population size is also an important factor in the rate of evolution of herbicide resistance. Where gene flow between adjacent populations is zero, the probability of a resistant individual occurring in a population is a function of population size (weed density × population area) and the initial gene frequency. While mutation rates and hence initial gene frequencies are beyond the control of management, weed population densities are not. Weed control practices that maintain low weed densities can considerably decrease the chance of resistance evolution by reducing the number of resistance alleles in a population (Christoffers, 1999).

A practical consequence of this principle, where more than one rare resistance gene is present in the population, is that individuals with multiple resistances are *extremely* rare prior to herbicide selection (Gressel & Segel, 1990). Hence, within any given local area, multiresistant individuals will, on balance of probabilities, be absent in any one generation.

Rotations and mixtures of herbicides that have discrete modes of action and that are not capable of degradation by a common metabolic pathway (mode of degradation) have long been proposed as a means to prevent or delay resistance evolution (Gressel & Segel, 1990; Wrubel & Gressel, 1994; Powles *et al.*, 1997). Powles *et al.* (1997) modelled herbicide resistance evolution in a weed population of infinite size when two herbicides were rotated annually or used each year as a mixture. In the absence of fitness penalties, (which would cause selection against resistant alleles in 'off' years) the rotation strategy did not increase the number of applications before resistance for either herbicide. When the herbicides were used in mixture, resistance was delayed by approximately 4 years.

When an infinite population is assumed, no matter how improbable, extremely rare double-resistant individuals will always be assumed to be present and influencing the rate of evolution of resistance. By explicitly simulating all genotypes in a finite population a more realistic prediction of the dynamics of the evolutionary process can be achieved. This capability is particularly important when examining the implications of patterns of herbicide use and may modify the relative benefits of alternative herbicide use strategies.

The model described in this paper was developed to investigate the influence of weed life history traits (seed dormancy and plant mating system) and management (population size and genetic isolation) on the rate of resistance evolution under three contrasting herbicide management regimes.

Model development

Overview

The model has been developed to simulate the evolution of herbicide resistance at two discrete, unlinked nuclear gene loci in a weed of broad-area farming. In accordance with most cases where the inheritance of herbicide resistance has been documented (Darmency, 1994) resistance is assumed to be conferred by alleles at a single gene locus. Mutant alleles at these two loci confer resistance to different herbicide modes of action so that evolution of resistance to two distinct herbicides or herbicide modes of action can be tracked within a single weed population (multiple resistance). It is assumed that alleles at the two loci segregate independently.

The herbicides to which resistance is being simulated are hypothetical. Both allow selective post-emergence control of the weed and both are effective enough so that the weed is adequately controlled when either herbicide is used on its own, resulting in 'redundant kill' [control of resistant survivors of one herbicide by a second, chemically dissimilar, herbicide as defined by Comins (1986)] when they are used in combination. There is no capacity for resistance at one locus to confer cross-resistance to other herbicide chemistries. The majority of herbicide resistance traits are inherited in a dominant or semi-dominant manner (Darmency, 1994). Resistance to both herbicides in this model is assumed to be inherited in a completely dominant manner at field-applied rates.

The model is constructed from a number of submodels and is based on the life cycle of a

hypothetical annual weed. The life cycle model simulates the population biology and demographics of a single population over successive generations. The reference point for the life cycle is the soil seedbank. Processes of germination, emergence, establishment, growth and reproduction are regulated by intrinsic population dynamics (density dependence and seedbank dynamics) and extrinsic environmental (climate) and management factors. Population dynamics and the efficacy of weed control strategies together govern transition probabilities between life history stages (Fig. 1).

The model was implemented in the Stella simulation language (version 7) produced by High Performance Systems, Inc., Hanover, NH, USA (http://www.hps-inc.com).

A crop (wheat, *Triticum aestivum* L.) is sown during each year of the simulation. Crop seeding and germination rates and crop establishment characteristics are defined. Competition between the crop and the weed is simulated using a reparameterized version of the hyperbolic equation (see below) used by Firbank and Watkinson (1986) to predict crop yields and weed seed production.

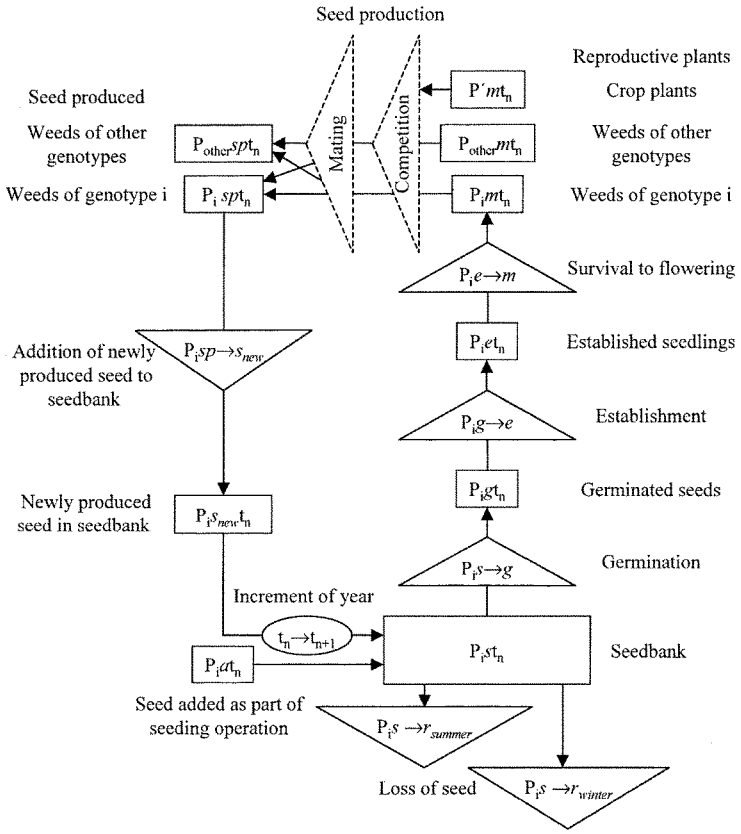


Fig. 1 Life cycle of the weed as represented in the model, illustrated for one genotype (i). Variables representing densities of plants in particular life history stages are enclosed in rectangles. Variables representing transition probabilities between life history stages are enclosed in continuous triangles. More complex relationships between stages are illustrated by broken triangles.

A weed population genetics submodel tracks the fate of herbicide-resistant and susceptible genotypes and alleles within the population. Control efficacies and population dynamics are defined individually for each of the nine possible weed genotypes (see below). A stochastic extinction routine is incorporated into the model to account for the possibility that rare alleles may be totally eradicated from the population.

During the reproductive stage, alleles at the two loci segregate independently into gametes (pollen and ovules) and recombine during completely random mating. The rate of out-crossing may be varied. Following seed-set and maturation, seeds are returned to the soil seedbank.

Weed life cycle

As with previous models of herbicide resistance, the life cycle forms the central element of the model through which changes in population density and the frequency of individual genotypes are accounted. During each generation, individuals of weed population (P) are represented in a number of states; viable seeds in the seedbank (s), germinated seeds (g), established seedlings (e), mature plants (m), seed produced on mature plants (sp), seed removed from the seedbank other than by germination (r), and seed added to the seedbank as a contaminant at crop sowing (a). The starting point for all simulations is the initial weed seedbank (Ps_{initial}) (seeds m^{-2}). The number of mature plants of genotype i in year n (P_imt_n) is defined by equation 1:

$$P_imt_n = (P_ist_n + P_iat_n)\ \ Ps{\rightarrow}g\ Pg{\rightarrow}e\ P_ie{\rightarrow}m, \quad (1)$$

where P_ist_n is the weed seedbank of genotype i in year n, P_iat_n is weed seed of genotype i added to the seedbank as part of the sowing operation in year n, $Ps{\rightarrow}g$ is the fraction of the weed seedbank which germinates, and $Pg{\rightarrow}e$ and $P_ie{\rightarrow}m$ are transition probabilities for individuals becoming established seedlings and mature plants respectively.

Total seed production (P_{sp}) is calculated in a separate competition submodel (see below). The total amount of seed of each genotype that is returned to the soil seedbank at the end of the growing season ($P_is_{\text{new}}t_n$) is the product of total seed production of genotype i in year n ($P_i\text{sp}t_n$) and the fraction of seed produced that reaches the seedbank ($P_{\text{sp}}{\rightarrow}s_{\text{new}}$).

The weed seedbank at the start of the following year (P_ist_{n+1}) is calculated as

$$P_ist_{n+1} = \{[1 - Ps{\rightarrow}g(P_ist_n + P_iat_n)](1 - Ps{\rightarrow}r_{\text{winter}}) + P_is_{\text{new}}t_n\}(1 - Ps{\rightarrow}r_{\text{summer}}), \quad (2)$$

where $Ps{\rightarrow}r_{\text{winter}}$ and $Ps{\rightarrow}r_{\text{summer}}$ are the fractions of ungerminated weed seeds lost from the seedbank during winter and summer respectively.

Crop/weed competition submodel

Competition between crops and weeds is simulated using a modified version of the hyperbolic function used by Firbank and Watkinson (1986):

$$P_{\text{sp}} = \frac{Pm\ P_{\text{sp max}}\ kP}{1 + (Pm\ kP) + (P'mk\ P'\ A)}, \quad (3)$$

where Pm is the number of mature weed plants, $P'm$ is the number of crop plants, $P_{\text{sp max}}$ is the potential maximum seed production of the weed per unit area, kP is the weed plant size coefficient, the inverse of the weed density (Pm) at which seed production is half of the predicted maximum ($P_{\text{sp max}}$), kP' is the crop plant size coefficient and A is the interspecific antagonism of the weed species by the crop.

Population genetics submodel

The model tracks the frequencies of herbicide-susceptible and resistant alleles at two discrete, independently segregating loci. The two loci confer resistance to two hypothetical herbicides, designated Y and Z, with different modes of action. Both loci are diallelic with the susceptible wild type alleles designated by lower case letters (y and z) and the initially rare mutant resistant alleles by upper case (Y and Z). Resistance alleles are specified as dominant. The model accounts for the frequency of nine genotypes within a single weed population (P_{YYZZ}, P_{YYZz}, P_{YYzz}, P_{YyZZ}, P_{YyZz}, P_{Yyzz}, P_{yyZZ}, P_{yyZz} and P_{yyzz}).

The initial weed population size is the product of the initial seedbank density (Ps_{initial}) and the area (m^2). The initial frequencies of resistant alleles Y and Z are defined as f_{Y} and f_{Z}, respectively, and alleles, assumed initially to be in Hardy–Weinberg equilibrium, are explicitly accounted thereafter.

Extinction

To avoid anomalous results resulting from fractional numbers of plants, the model represents small populations as integer values. Where less than 10 individuals of any genotype are calculated to occur at any stage of the life cycle, an integer number of individuals is derived assuming that the calculated weed density is a probability of occurrence in a Poisson process (Vose, 2000). Where 10 or more individuals are expected, the probability that an extinction event would occur in a Poisson process is less than 1 in 20 000. If the populations of all genotypes that contain any particular allele are resolved to 0 at any time then that allele is considered extinct and will remain extinct unless it is reintroduced as a contaminant during sowing. Random numbers conforming

to Poisson distributions were generated using the Stella simulation software with sequences of random numbers seeded using the system clock. Because the extinction process is effectively random, repeated runs of the model with identical parameters will produce different outcomes.

Mating

Resistance alleles segregate independently. The fraction of self-pollination in the weed species can vary between 1 (autogamous) and 0 (allogamous). The frequencies of pollen haplotypes for each plant genotype are the averages of the frequencies for that plant genotype and the frequencies for the total plant population weighted according to the self-pollination fraction. Ovules and pollen are produced in direct proportion to predicted seed yields and all gamete haplotypes have an equal chance of reproductive success (pollination, embryo development and seed maturation).

Pollen and ovule haplotypes recombine at random to produce diploid zygotes that develop into mature seed. The simplifying assumption of random recombination within the weed population is common to existing models that assume infinite populations, but it is inaccurate because of uneven spatial distribution of genes within the population. This assumption of random recombination becomes less realistic as the simulated area becomes greater, and it will tend to result in an overestimation of the rate that resistant alleles multiply after multi-resistant individuals develop. However, once resistance has developed it is reasonable to assume that it will eventually spread throughout the population. The randomness of recombination does not influence the probability that rare alleles will be present in finite populations and hence it should have minimal influence on the probability that resistance will develop initially.

Parameter values

Weed management practices, together with intrinsic population processes (mortality, loss of viability and competition), act in conjunction to regulate weed population dynamics and ultimately, weed densities in the field. In the model, these processes are defined by the parameters that affect the probability of any individual moving from one life history stage to the next (e.g. from germinated seeds to established seedlings). These parameters have been adapted from those presented by Pannell *et al.* (2003) to approximate conditions and management typical of wheat grown in the cropping belt of Western Australia.

All parameter values are constant for all genotypes of the weed except for the probability that established seedlings will become mature plants ($P_l e \rightarrow m$), which is affected by application of post-emergence herbicides. The values for all constant parameters are given in Table 1. The probability that established seedlings will become mature plants ($P_l e \rightarrow m$) is the product of the probabilities that plants will survive application of herbicides Y and Z ($P_l e \rightarrow m_Y$ and $P_l e \rightarrow m_Z$ respectively). The probabilities of genotypes surviving when herbicides are applied are presented in Table 2. Where herbicides are not applied $P_l e \rightarrow m$ is 1.

We have chosen not to include density-dependent mortality of plants because we anticipate that plant densities will typically be low while herbicides are still effective. For this reason, density-dependent mortality is unlikely to be an important factor in the dynamics that affect initial development of herbicide resistance.

Table 1 Descriptions, variable names, values and units for constant parameters

Parameter description	Variable name	Value	Unit
Density of crop plants	$P'm$	100	plants m^{-2}
Initial weed seedbank	$Ps_{initial}$	100	plants m^{-2}
Initial frequency of allele for resistance to herbicide Y	f_Y	10^{-6}	
Initial frequency of allele for resistance to herbicide Z	f_Z	10^{-6}	
Annual import of unselected weed seed	Pat_n	0.1	plants m^{-2}
Fraction of weed seedbank lost in winter	$Ps \rightarrow r_{winter}$	0.1	
Fraction of weed seedbank lost in summer	$Ps \rightarrow r_{summer}$	0.1	
Fraction of germinated seed that establishes as seedlings	$Pg \rightarrow e$	0.2	
Fraction of seed produced on weeds that reaches the seedbank	$P_{sp} \rightarrow s_{new}$	1	
Maximum viable weed seed production	$P_{sp\ max}$	30000	plants m^{-2}
Weed plant size coefficient	kP	0.04	m^2 $plant^{-1}$
Crop plant size coefficient	kP'	0.09	m^2 $plant^{-1}$
Crop/weed antagonism parameter	A	1.3	

Table 2 Probabilities that plants of specified genotypes will survive applications of herbicides Y and Z

Genotype for gene Y	yy	Yy	YY
Value of $P_e \rightarrow m_Y$ when herbicide Y is applied	0.05	1	1
Genotype for gene Z	zz	Zz	ZZ
Value of $P_e \rightarrow m_Z$ when herbicide Z is applied	0.05	1	1

Accuracy of the model is less important in circumstances where herbicide resistance has already developed and weeds have reached high densities. Such situations are unlikely to occur in practice as farming would not be profitable and farmers would alter their practices accordingly.

Plant life history strategies

Four contrasting plant types were specified for the weed population. These plant types were combinations of high and low germination fraction ($Ps \rightarrow g = 0.9$ or 0.1) and high and low self-pollination fraction (0.99 or 0). All constant weed related parameters have been chosen to approximate *Lolium rigidum* Gaud. (annual ryegrass), which is cross-pollinated and has a high germination fraction similar to that specified above.

Herbicides and herbicide use patterns

In all simulations two herbicides (Y and Z) were available for post-emergence control of the weed population. Both herbicides achieve 95% control of susceptible individuals (see Table 2), they have distinct modes of action and cannot be degraded by a common metabolic pathway (there is no potential for evolved cross-resistance to both herbicides). In the absence of herbicide application there is no fitness penalty associated with resistance to either herbicide. Fitness penalties associated with target-site resistance to the triazine herbicides have been documented in a number of weed species. However, the results for resistance to all other herbicide modes of action have been more equivocal (Holt & Thill, 1994).

Three patterns of herbicide application were defined. These were:

Rotation strategy: Herbicides Y and Z were applied in alternate years beginning with Y in the first year.

Threshold strategy: Herbicide Y was applied in all years until the frequency of the Y resistance allele (Y) exceeded a threshold value of 0.01, after which point Z was applied until the frequency of the Z resistance allele (Z) exceeded the same threshold, whereafter whichever herbicide had the lowest fraction of resistance was applied. Please note that we are using this term in a non-standard way to refer to thresholds of frequencies of resistance alleles rather than thresholds of weed density.

Combination strategy: Both herbicide Y and Z were applied in all years. There were no antagonistic or synergistic interactions between the two herbicides. It is important to note that this strategy involves application of more herbicide than does either of the other two strategies.

For each plant type in combination with each herbicide application strategy 32 repeated 50-year simulations were conducted for each of 19 treatment areas ranging from 10^2 m^2 to 10^8 m^2 on a log scale.

Results

Each model run results in a time series of populations of the nine genotypes. For simplicity these can be identified as four phenotypes: susceptible to both herbicides (yy zz); resistant to Y only (yY zz and YY zz); resistant to Z only (yy zZ and yy ZZ); resistant to both Y and Z (yY zZ, YY zZ, yY ZZ and YY ZZ).

While each of the runs is unique due to stochastic processes, runs that gave similar results can be grouped according to the characteristic dynamics of the populations (seedbanks). For each of the 32 runs of the model for each combination of plant type by herbicide strategy at each treatment area, three outcomes were possible: no resistance develops; resistance develops to a single herbicide; resistance develops to both herbicides.

For example, the outcrossing high germination fraction plant type produced eight typical patterns of seedbank behaviour (Fig. 2). Where no resistance developed the population steadily declined (Fig. 2A and B). This decline was typically more rapid where the herbicides were used in combination (Fig. 2C).

Where herbicides were used in rotation and resistance developed to either of the two herbicides, the population of resistant plants increased exponentially and exceeded the population of susceptible plants at around year 10 (Fig. 2D). From that time the population of resistant plants increased rapidly until stabilizing at numbers in excess of 10 000 seeds m^{-2}. There was also a transient increase in the population of susceptible plants as a consequence of recombination amongst the progeny of heterozygous resistant plants (i.e. yY or zZ). The population of susceptible plants ultimately fell as the frequency of the susceptible allele (i.e. y or z) declined.

In cases where a single resistance emerged under the threshold strategy, control of the population was maintained by the use of the alternate herbicide, with the population of resistant plants remaining below 10 plants m^{-2} (Fig. 2E).

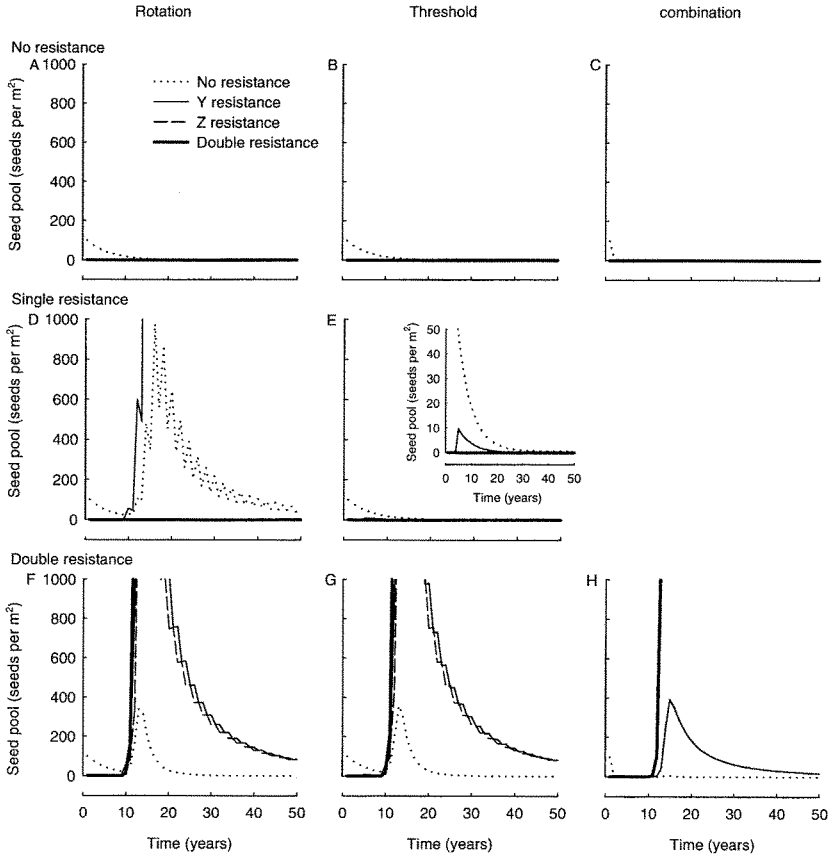


Fig. 2 Selected examples of typical time series of seed pool size for the four phenotypes of the plant type with 0.9 germination fraction and 0 self-pollination fraction for the three classes of developed resistance (rows) for each of the patterns of herbicide use (columns). The probabilities of these typical outcomes vary with treatment area (see Figs 4 and 5).

In all cases where double-resistance developed, the population of double-resistant plants increased rapidly from about year 10 (Fig. 2F–H). Transient increases in the populations of the other three genotypes occurred in response to the recombination effects as described for single resistance (Fig. 2D).

Variations occurred in the timing of development of resistance. In general, resistant populations increased more slowly where the germination fraction was low (0.1) (data not shown). For all types of resistance there were examples where build up of resistance was delayed. An example illustrating development of double-resistance with delayed occurrence of Z resistance is shown in Fig. 3. Delayed resistance of this sort occurred where resistance genes in the initial population became extinct but were reintroduced in contaminant seed.

All model runs were categorized according to the highest resistance status attained by the population during the simulated 50-year period, namely: no resistance; Y resistance only; Z resistance only; and double-resistance. The relative frequencies of these categories

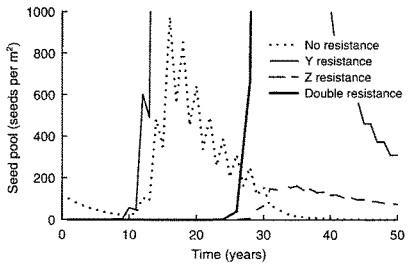


Fig. 3 An example time series of seed pool size for the four phenotypes of the plant type with 0.9 germination fraction and 0 self-pollination fraction illustrating development of double-resistance where Z resistance is delayed. Herbicides were applied in rotation with a 21.4 ha treatment area.

varied in response to the treatment area (≡ initial population size).

For the cross-pollinated plant type with high germination fraction (0.9) for all herbicide use patterns, development of resistance was rare in the smallest treatment areas (Fig. 4). As the area increased, the frequency of single resistances and, subsequently, double-resistance increased. This trend occurred because the probability of extinction of resistance genes decreases as area (≡ initial population size) increases.

The relationship between probability that no resistance would occur and area treated was very similar where herbicides were applied in rotation or according to the threshold strategy (Fig. 4A). In both cases resistance always occurred in some form in treatment areas larger than 20 ha. Where herbicides were used in combination, resistance became frequent only in much larger areas. A treatment area in the order of 100 times larger was required to produce similar probabilities of development of resistance (Fig. 4A).

Where herbicides were applied in combination, resistance to either Y or Z alone did not occur because plants with resistance to only one herbicide were adequately controlled by the other herbicide. Consequently, only populations of double-resistant plants were able to increase. Resistance to herbicide Z alone did not occur where the threshold strategy was used (Fig. 4B). This is because according to this strategy herbicide Z was only applied after resistance to herbicide Y had developed.

Where herbicides were applied in rotation, Y resistance tended to occur more frequently than Z resistance because Y was the first herbicide applied in the rotation (Fig. 4B). Consequently the population initially treated by Z was reduced, increasing the probability of extinction of the Z resistance allele.

The relationship between probability of occurrence of resistance and treatment area was broadly similar for all plant types, but the relative effect of using herbicides in combination was larger for plant types with lower germination fraction or higher fraction of self-pollination. For self-pollinated weeds with a high germination fraction, a treated area in the order of 1000 times larger was required to produce similar probabilities of development of resistance for herbicides used in combination vis-à-vis the other strategies (Fig. 5A). This factor was greater than 10 000 times for weeds with low germination fraction (Fig. 5D and G). In the case of self-pollinated weeds with low germination fraction

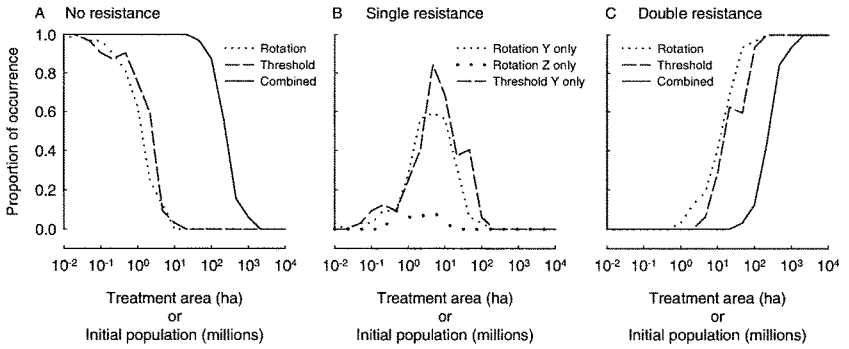


Fig. 4 Proportion of simulation runs where no resistance occurred (A), where resistance to a single herbicide type occurred (B) or where resistance to both herbicide types occurred (C) versus treatment area (≡ initial population size) for the plant type with 0.9 germination fraction and 0 self-pollination fraction.

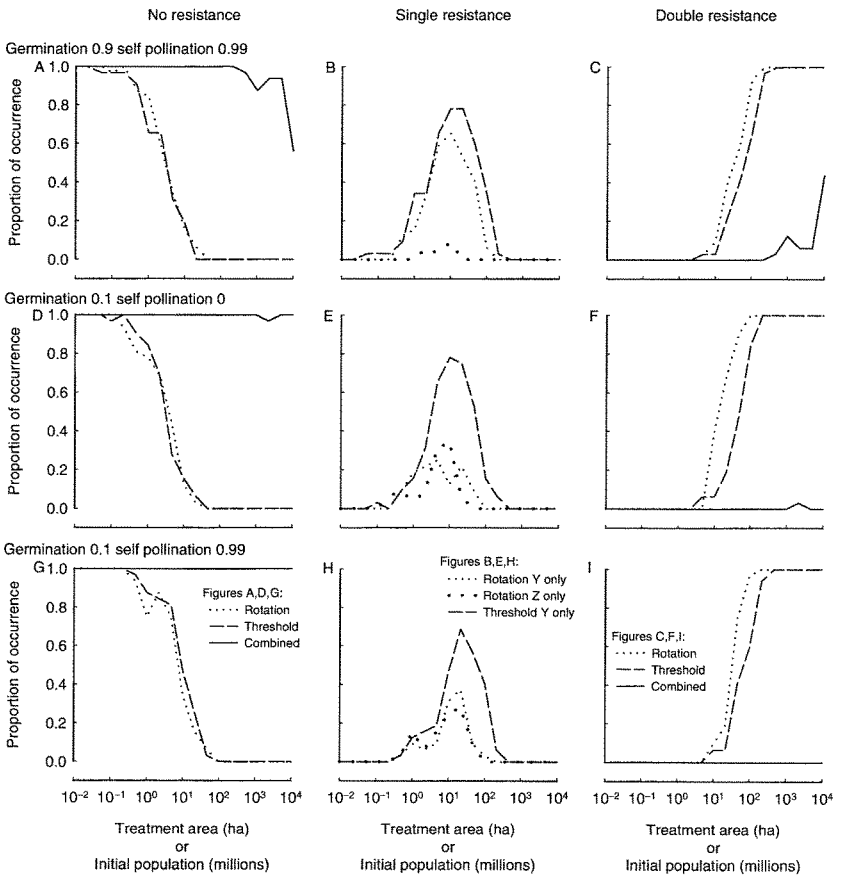


Fig. 5 Proportion of simulation runs where no resistance occurred (A, D and G), where resistance to a single herbicide type occurred (B, E and H) or where resistance to both herbicide types occurred (C, F and I) versus treatment area (≡ initial population size) for three plant types (in rows).

herbicide resistance was never observed where herbicides were used in combination (Fig. 5G).

Where herbicides were applied in rotation, germination fraction had an effect on the relative frequencies of the two types of single resistance. Where germination fraction was low a smaller fraction of the population was exposed to Y in the first year, hence the probability of extinction of the Z resistance allele was reduced and the frequency of Z resistance was higher (Fig. 5E and H versus Fig. 5B).

For all plant types the transition from single resistance to double-resistance occurred at marginally larger treatment area under the threshold strategy than under the rotation strategy (Figs 4C, 5C, F and I).

Under all strategies the transition to increased levels of resistance occurred at marginally larger areas for self-pollinating plant types than for outcrossing plant types (Fig. 4A–C versus 5A–C and 5D–F versus 5G–I). This is due to the decreased incidence of heterozygous-resistant individuals in populations of self-pollinated plants.

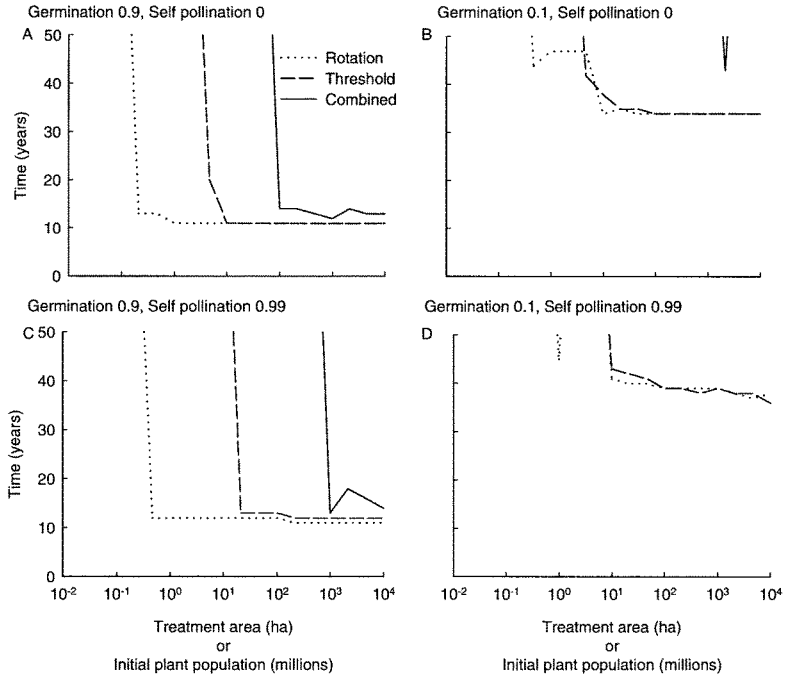


Fig. 6 Year of the time series where the average size of the weed seed pool for all replicate simulation runs exceeded 1000 seeds m^{-2} versus treatment area (≡ initial population size) for the three patterns of herbicide application for the four plant types in separate figures.

The timing of appearance of large populations (indicating the development of resistance) differed markedly between the plant types with high and low germination fractions (Fig. 6). The time taken for the seedbank to exceed 1000 seeds m^{-2} was approximately three times greater in low germination fraction types than in the high germination fraction types (Fig. 6A versus 6B and 6C versus 6D). Where germination fraction is lower a smaller proportion of the population is exposed to herbicides in each year, effectively slowing the rate of resistance evolution in those populations.

At small treatment areas, where resistance generally did not develop, the mean populations never exceeded 1000 seeds m^{-2}. The minimum treatment area where the seed pool did exceed this value was lowest where herbicides were used in rotation and highest where they were used in combination.

For large treatment areas for all plant types the increase in seedbank was equally rapid for the rotation and threshold strategies. In the high germination fraction populations the increase in plant population was only marginally slower where herbicides were used in combination (Fig. 6A and C). In low germination fraction populations the mean seed pool generally did not reach 1000 seeds m^{-2} under the combination strategy (Fig. 6B and D).

Discussion

The importance of population size in relation to rare genes

The first major conclusion from this study is that minimizing the effective weed population size substantially decreases the rate of evolution of herbicide resistance. Clearly, the smaller a population is, the less likely it is that rare resistance genes will be present in the population. Even where resistance genes do occur at low frequencies in small populations, stochastic demographic processes are more likely to result in the extinction

of these genes. When considering two resistance genes, as we have simulated here, the probability of both genes occurring in the same individual is orders of magnitude smaller again. Management practices that effectively segregate weed populations into smaller, genetically isolated units will, therefore, result in a lower incidence of herbicide resistance.

The degree to which weed populations can be segregated and contained will depend in large part on the movement of genes in pollen and seeds or propagules. Gene flow in pollen is something over which land managers have little or no control. However, Maxwell (1992) showed that only 7% of pollination events occurred at distances greater than 1 m in diclopfop-methyl-resistant *Lolium multiflorum* Lam. Rieger *et al.* (2002) have shown that pollen-mediated gene flow from herbicide-resistant to non-herbicide-resistant oilseed rape (*Brassica napus* L.) crops does occur over considerable distances, but only at very low frequencies. Where a weed species has a high degree of outcrossing and viable pollen can travel long distances from source populations, the goal of genetic isolation may be unattainable.

Gene flow by seed movement is a factor that land managers can influence because for many agricultural weeds farm management largely dictates mobility of the seed. Through strict farm hygiene, land managers can limit the importation of weed seed to a farm, the movement of seed between fields on a farm and movement of seed within fields. This may involve improved screening of seed and fodder brought on to the farm to ensure it is free of weeds; the cleaning of machinery between segregated areas; and the catching of weed seeds during the grain harvest so that they are not redistributed. The situation is analogous in many ways to that of a newly invading weed species, except that in this case the 'invading weed' is not visually distinguishable from the existing weed population. Management strategies that reduce rate of movement of the weed would be expected to increase the time until herbicide resistance becomes a problem in areas where resistant individuals were initially absent.

The importance of pattern of herbicide application

A second major conclusion is that rotation of herbicides, commonly recommended as a strategy to delay the development of herbicide resistance in weeds (Powles & Shaner, 2001), is markedly inferior to the use of herbicides in combination, and is not superior to an 'expend and swap' approach typified by the threshold strategy discussed here. This conclusion is contingent on the validity of the first conclusion and on the assumptions made, i.e. that both herbicides achieve efficacy that is high enough to ensure 'redundant kill' (are used at full rates), are not subject to linkage disequilibrium, are not associated with fitness costs and have different modes of action (no cross-resistance).

For large effective areas (population size) there is very little effect of pattern of herbicide application. However, for effective areas less than 100 ha, there was a marked advantage in using the 'combination' strategy in all scenarios tested here. The range of initial populations for which the combination strategy was superior varied markedly with germination fraction and degree of self-pollination in the weed, but it is likely that an effective initial population within this range is achievable for most agricultural weeds, particularly where initial population density is low and where the weed is self-pollinated. The utility of pesticide mixtures as opposed to a threshold approach has been similarly demonstrated for insecticide resistance management (Mani, 1985). However, Comins (1986) qualifies this 'redundant kill' strategy by indicating that it will only be effective where population size is small. The results presented in this paper agree with these conclusions.

It must be noted that the combination strategy has disadvantages that should be considered before deciding to use it in practice. Two of these disadvantages are the cost and the possible ecological implications of using more herbicide. Furthermore, the cost of using more herbicide is immediate, while the returns from delayed occurrence of herbicide resistance will be realized in the future and hence, by classic economic theory, will be reduced in terms of present value.

Another factor that must be considered is that the combination strategy requires farmers to apply two herbicides to control a weed even when the density of that weed is extremely low. Such a strategy could be considered counter intuitive. However, in Western Australia, where many farmers have first hand experience with herbicide resistance in weeds which are difficult to control, a form of the combination strategy is currently recommended to delay the occurrence of glyphosate resistance (Neve *et al.*, 2003).

Previous modelling of herbicide use strategies that have assumed infinite population sizes (which are analogous to the largest population sizes simulated here) have considerably underestimated the benefits of herbicide mixtures and sequences as management tools to prevent or delay herbicide resistance. Such models do not account for the strategically important possibility of local extinction of rare alleles. While the methodology we have used does not explicitly simulate spatial processes, the results do indicate that a quantitative understanding of the spatial dynamics of resistance genes is very important to a fuller understanding

of evolution of herbicide resistance. Improved quantitative understanding of the spatial dynamics could be achieved by embedding a model similar to the one presented here in a spatial framework such as that presented by Richter *et al.* (2002) for the one gene case. With the model presented here it appears highly likely that the rate of development of herbicide resistance can be limited by reducing movement. Furthermore, where movement can be limited, a strategy that uses herbicides in combination would be superior to rotation of herbicides in terms of rate of evolution of resistance.

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Feature

Predicting the Evolution and Dynamics of Herbicide Resistance in Weed Populations[1]

BRUCE D. MAXWELL, MARY LYNN ROUSH, and STEVEN R. RADOSEVICH[2]

Abstract. Herbicide resistance jeopardizes the usefulness of valuable chemical tools and, therefore, weed management in many crop systems. Models must be developed to evaluate management tactics that prevent, delay, or reduce resistance. The complexity of biological processes involved in herbicide resistance also requires models to focus research and to integrate experiments. A population model was developed that improves upon previous attempts to predict herbicide resistance dynamics. The model incorporates plant population demographics with the Hardy-Weinberg concept for gene segregation. The model simulates the evolution, spread, and subsequent dynamics of resistance in the presence and absence of a herbicide. Analysis of model simulations identified two sets of biological processes as key factors in the evolution and dynamics of herbicide-resistant weed populations. These are processes that influence ecological fitness and gene flow. Several options are suggested as examples for the management of resistant weed populations.
Additional index words: Population model, resistance management, seed immigration, pollen immigration, population genetics.

INTRODUCTION

Herbicides are used extensively in agriculture because they are cost-effective tools to reduce weed abundance and to improve crop yields. Recent trends in herbicide development have produced extremely specific and selective chemicals that are used intensively and routinely in cropping systems. The intensive and widespread use of such herbicides has precipitated an alarming increase in the evolution of resistance (9, 15, 28), which jeopardizes product usefulness, availability, and longevity (15). Since the first reported cases of herbicide resistance (26, 27, 30), over 50 plant species resistant to triazine herbicides have been reported (25). In addition, numerous weed species have developed resistance to chemical classes of herbicides other than triazines (13, 22, 33, 35).

The complexity of biological processes that influence herbicide resistance dictates a research approach that focuses on the interaction between life history processes and population genetics. Models can serve such a function and can provide a tool for evaluating management tactics. Review papers on the population biology of pesticide resistance have indicated similar approaches for studying and managing resistance (7, 19, 29, 34, 36, 37). Gressel and Segel (10, 11) developed a model that suggested important factors that influence occurrence and evolution of herbicide resistance. However, their model did not include the gene flow processes of immigration and important factors influencing fitness that may improve prediction of local evolution, spread, and subsequent dynamics of the R[3] trait in a S[3] population of weeds.

Population processes that determine the relative fitness of phenotypes are survivorship (demography of seeds, seedlings, and mature plants), fecundity (pollen and seed production), and plant competition. When a herbicide is used, its selection pressure (reduced survivorship of susceptible individuals) overwhelmingly increases the relative fitness of the resistant genotype (10, 11). However, when herbicide selection pressure is removed, population dynamics are determined by differences in all processes that contribute to the fitness of each biotype.

We have developed a population model that simulates the evolution, spread, and dynamics of R and S weed biotypes (Figure 1 and Table 1). This model improves upon the biological interpretations suggested by Gressel and Segel (10, 11) and provides a refined approach for evaluating the importance of specific biological processes involved in the dynamics of herbicide resistance. The model combines plant population demographics (18, 21) and the Hardy-Weinberg equation (2, 3) to determine proportions of R and S genotypes in successive generations.

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[3]Abbreviations: R, herbicide resistant; S, herbicide susceptible.

Many herbicides inhibit a specific enzyme that can be coded for by a single gene; thus, use of the Hardy-Weinberg inheritance model is a reasonable approach. The model incorporates differential fitness (i.e., survivorship, competitive ability, and fecundity) of R and S genotypes in the presence and absence of a herbicide (selection pressure). Genotype proportions also are modified by gene flow (i.e., immigration, seed bank dynamics, inbreeding, and random genetic drift) and by mutation.

Simulations using this model predict rapid early evolution of resistance from repeated herbicide applications in the absence of an adjacent source population of the S phenotype (Figure 2). After herbicide use is suspended, the model forecasts a decline in resistance with return to populations dominated by the S type. The rate of decline in resistance depends on life-history processes, immigration processes, mechanisms of inheritance, reproductive mechanisms, and the relative fitness of the R and S phenotypes.

MODEL DEVELOPMENT

The model, like earlier herbicide resistance models (8, 10, 11), is theoretical. It was developed to generate hypotheses on the influence of demographic and inheritance processes on resistance evolution and management. The simulation model was constructed by linking eight submodels representing life-history stages (seed bank, seedling, mature plants, pollen producers, seed yield), immigration, and inheritance (Figure 1). This structure allows alternative submodels to be inserted and tested as new information on particular processes becomes available.

The current model assumes for mathematical simplicity that the weed is a single-cohort (one germination time) annual, that all parameters are held constant over time unless indicated otherwise (Table 1), and that herbicide resistance is associated with a single gene locus. Thus, it is assumed that herbicide resistance is determined by a single pair of alleles, where **a** denotes the recessive allele and **A** the dominant allele. The computer model allows the user to select (Figure 3) if the genotype **aa**, the homozygous recessive, results in the R phenotype and **AA** and **As** represent S phenotype plants or if **aa** results in the S phenotype and **AA** and **Aa** are R. Throughout this paper the **aa** genotype was assumed to confer resistance. The model will allow for different inheritance patterns by inserting a different inheritance submodel. A separate description of each submodel follows.

Seed bank submodel. The number of R and S weed seed in the seedbank was assumed to be a function of seed mortality and germination rates for each phenotype. This amount is supplemented by the number of seed entering the seedbank from the treated population and seed immigration.

The number of R and S seed in the seedbank before germination (RSB and SSB, respectively) is expressed as

$$RSB = RSB_{t-1} + Ryld_{t-1} + RISD_{t;\ -\ Rm}(RSB_{t-1}) \quad [2.1]$$

$$SSB = SSB_{t-1} + Syld_{t-1} + SISD_t - S_m(SSB_{t-1}) \quad [2.2]$$

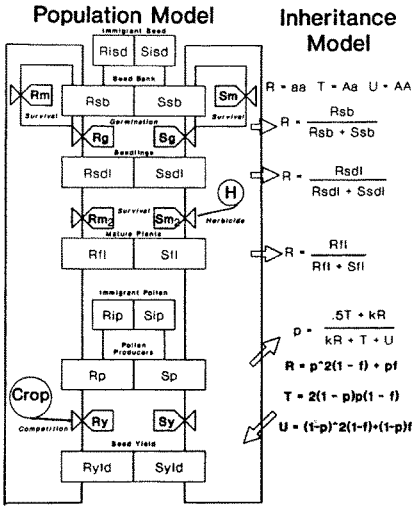


Figure 1. A representation of the model that follows life-history sages of resistant and susceptible biotypes and incorporates the influences of fitness processes and gene flow. Open arrows indicate the flow of information between the population model and the inheritance model. State variables are named above each box and processes are indicated in italics. Abbreviations are explained in the text and Table 1.

Table 1. Definitions used in the development of the herbicide resistance model (see Figure 1).

Parameter	Definition and default values	Equation number
t	Current generation	
Immigration parameters		
a_{sd}	The number of pollen-produced per unit area by the source population. a_{sd} = TOT = model input value (Figure 5).	1.1
a_p	The number of pollen-producing plants per unit area representing the total amount of pollen produced by the source population. $a_p = a_{sd}/10$. 5.1	
x′	The distance from the center of the source population to the center of the treated population.	1.1 & 5.1
c_s	The radius of the total source area (Figure 4).	1.1 & 5.1
c_o	The radius of the interior source population that is equal to the treated population radius (0.5) (Figure 4).	1.1 & 5.1
c	The square root of the scaling factor $[c = (c_s^2/c_o^2)^{\frac{1}{2}}]$ (Figure 4).	
bp	The steepness of the diffusion gradient for pollen (1.7).	5.1
bsd	The steepness of the diffusion gradient for seed (7.4).	1.1
Demographic parameters		
RSB	The number of R seed in the seed bank before germination.	2.1
SSb	The number of S seed in the seed bank before germination.	2.2
R_m	The proportion of R seed that die over 1 generation in the seed bank (0.7).	2.1
S_m	The proportion of S seed that die over 1 generation in the seed bank (0.7).	2.2
ISD	The total number of seed added to the seed bank through immigration over 1 generation.	1.1
RISD	The number of immigrant seed that is R-phenotype.	2.1
SISD	The number of immigrant seed that is S-phenotype.	2.2
R_g	The proportion of R seed that germinate over 1 generation (0.3).	2.3
S_g	The proportion of S seed that germinate over 1 generation (0.3).	2.4
RSDL	The number of R seedlings produced from seed germinating in the seed bank.	3.1
SSDL	The number of S seedlings produced from seed germinating in the seed bank.	3.2
R_{m2}	The proportion of R seedlings that die over 1 generation (0.75).	3.3
S_{m2}	The proportion of S seedlings that die over 1 generation (0.75).	3.4
RFL	The number of R mature (flowering) plants.	4.1
SFL	The number of S mature (flowering) plants.	4.2
h	Herbicide efficacy on seedlings (95%).	4.2
IP	The total number of pollen-producing plants represented by immigrant pollen.	5.1
RP	The number of R pollen-producing plants represented by immigrant pollen.,	6.1
SP	The number of S pollen-producing plants represented by immigrant pollen.	6.2
TM	The total number of mating plants.	7.7
TMr	The number of mating plants that will produce R seed.	7.8
TMs	The number of mating plants that will produce S seed.	7.9
RY	The number of R seed produced per R plant.	8.1
SY	The number of S seed produced per S plant.	8.2
Ryld	The R seed yield per unit area.	8.3
Syld	The S seed yield per unit area.	8.4
Tyld	The seed yield per unit area with genotype Aa.	2.7
Inheritance parameters		
Rsb	The proportion of the seed bank that is R-phenotype.	2.5
Tsb	The proportion of the seed bank that is Aa genotype.	2.7
Usb	The proportion of the seed bank that is Aa genotype.	2.8
Ssb	The proportion of the seed bank that is S-phenotype.	2.6
Rsdl	The proportion of seedlings that are R-phenotype.	3.5
Tsdl	The proportion of seedlings that are Aa genotype.	3.7
Usdl	The proportion of seedlings that are AA genotype.	3.8
Ssdl	The proportion of seedlings that are S-phenotype.	3.6

(continued)

Table 1. (continued) Definitions used in the development of the herbicide resistance model (see Figure 1).

Parameter	Definition and default values	Equation number
Inheritance parameters		
Rfl	The proportion of mature (flowering) plants that are R-phenotype.	4.3
Tfl	The proportion of mature (flowering) plants that are Aa genotype.	4.5
Ufl	The proportion of mature (flowering) plants that are AA genotype.	4.6
Sfl	The proportion of mature (flowering) plants that are S-phenotype.	4.4
Rof	The proportion of R pollen-producing plants in the outside (source for immigration) population.	1.2
Sof	The proportion of S pollen-producing plants in the outside (source for immigration) population.	1.3
Tof	The proportion of pollen-producing plants with Aa genotype in the outside (source for immigration) population.	2.7
Rp	The proportion of R pollen-producing plants in the treated population.	6.3
Sp	The proportion of S pollen-producing plants in the treated population.	6.4
Tp	The proportion of pollen-producing plants with Aa genotype in the treated population.	6.5
Up	The proportion of pollen-producing plants with AA genotype in the treated population.	6.6
p	The probability of an individual's donating the a allele in a mating.	7.1
kr	The fitness of the R pollen relative to the S pollen (0.9).	7.1
f	The inbreeding coefficient.	7.5
m	The forward mutation rate to resistance (10^{-6}).	7.5
Ne	The effective size of the population (related to the number of reproducing adults).	7.6
R	The proportion of the total matings that will produce R seed.	7.2
T	The proportion of the total matings that will produce seed with Aa genotype.	7.3
U	The proportion of the total matings that will produce seed with AA genotype.	7.4
S	The proportion of the total matings that will produce S seed.	7.4
RY_{max}	The maximum yield per R plant (900 seeds/plant).	8.1
SY_{max}	The maximum yield per S plant (1000 seeds/plant).	8.2
a_r	The area required to produce RY_{maxi} (1).	8.1
a_s	The area required to produce SY_{maxi} (1).	8.2
z_{sr}	The influence of S plant density on the seed yield of R plants (1).	8.1
z_{rs}	The influence of R plant density on the seed yield of S plants (1).	8.2
z_{ir}	The influence of another weed or crop plant (i) density on the seed yield of R plants (1.2).	8.1
z_{is}	The influence of another weed or crop plant density on the seed yield of S plants (1.1).	8.2
N_i	The density of the other weed or crop (200 plants/m^2).	8.1 & 8.2
br	The coefficient which determines the form of the relationship between RY_t and the total density (0.8).	8.1
bs	The coefficient which determines the form of the relationship between SY_t and the total density (0.8).	8.2

where $Ryld_{t-1}$ is the number of R seed produced per unit area by the previous generation and $Syld_{t-1}$ is the number of S seed produced per unit area by the previous generation in the treated population. The mortality rates for R and S seed are R_m and S_m, respectively.

Seed immigration submodel. Immigration of genes has two points of origin: seed and pollen from outside the treated population. The immigration of seed from an outside population is treated as an influx into the seedbank. Pollen immigration enters the model in the pollen producer submodel. The proportions of genotypes immigrating from a source are assumed to be the same as the proportions in the source (outside field) population. Emigration was not included in the model.

Seed immigration is a function of dispersal which involves several variables: a) heights and distance of the seed source, b) concentration at the seed source, c) dispersibility of the seed (e.g., weight, possession of wings, plumes, etc.) and d) activity of distributing agents (e.g., wind direction and velocity) (12). These variables are generally species specific and require specific models. In the current model, seed immigration is based on a diffusion gradient model used to predict a plant disease gradient (24) and pollen dispersal (6).

$$ISD_t = (a_{sd} (x' + c_o)^{-bsd}) (c_s^2 / c_o^2) \quad [1.1]$$

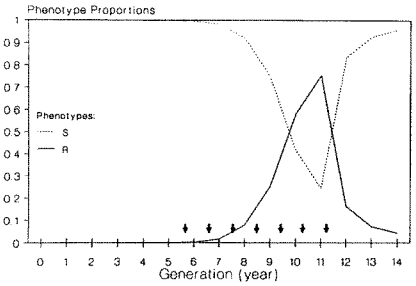


Figure 2. Model simulations describing the evolution of resistance when the herbicide is used in the system and the subsequent dynamics of resistance in the weed population after the herbicide has been removed. The solid arrows indicate the years of continuous herbicide use.

```
Mechanisms of Resistance Inheritance:
--------------------------------------

 1. Resistance is a recessive trait.

 2. Resistance is a dominant trait.

--------------------------------------

Choose a number?

        Reproductive mechanism:
        ------------------------------------------------

         1. Outcrossing with 7 % selfing.

         2. Selfing with 7 % outcrossing.

        ------------------------------------------------

        Choose a number?
```

Figure 3. The first input screen for RSIM (the interactive computer program version of the model) used for selecting the mechanism of resistance inheritance and the reproductive mechanism for a weed species of interest.

$$RISD_t = ISD_t(Rof) \qquad [1.2]$$

$$SISD_t = ISD_t(Sof) \qquad [1.3]$$

ISD is the total number of immigrant seed per unit area entering the treated population seedbank from outside populations (Figure 4). The parameter a_{sd} is the number of seed produced per unit area at $1–c_o$ units of distance from the center of the source, which is equivalent to the total number of seed produced by the source when it is equal in size to the treated population. Since the source was assumed to be equal in size to the treated population, it was also assumed that the source would produce the same amount of seed as the treated population.

The x′ parameter is the distance (in treated population diameters) from the center of the source population to the center of the treated (receptor) population, and c_o is a truncation factor which approximates the radius of a source population (23) in the center of the total source that is equal in size to the treated population (Figure 4). Setting all measures relative to the size of the treated population allows for assessment of immigration at all scales. The parameter bsd is the slope of a linear regression of log(Isd) on $\log(x' + c_o)$. To accommodate immigrant sources larger or smaller than the treated population, a scaling factor (c^2/ c_o^2) was added to the immigration equation, where c_s is the total source (a set of source populations) area radius in units of treated population diameters.

The number of R and S seed reaching the treated population as a result of immigration are RISD and SISD, respectively. The proportions of each genotype in the outside (source) population are Rof (genotype **aa**), Tof (genotype **Aa**), and Uof (genotype **AA**). The proportion of the susceptible phenotype in the source population is Sof = Tof + Uof.

After germination the numbers of R and S seeds that remain in the seedbank until the next generation are

$$RSB_t = RSB - R_g(RSB) \qquad [2.3]$$

$$SSB_t = SSB - S_g(SSB) \qquad [2.4]$$

where R_g and S_g are germination rates for R and S seed.

The proportion of each genotype (Rsb = **aa**, Tsb = **Aa**, Usb = **AA**) in the seed bank at time t is calculated by

$$Rsb_t = \frac{RSB}{RSB + SSB} \qquad [2.5]$$

$$Ssb_t = \frac{SSB}{RSB + SSB} \qquad [2.6]$$

$$Tsb_t = \frac{Tsb_{t-1}\,(RSB_{t-1} + SSB_{t-1}) + Tyld_{t-1} + ISD_t\,(Tof)}{RSB + SSB} \qquad [2.7]$$

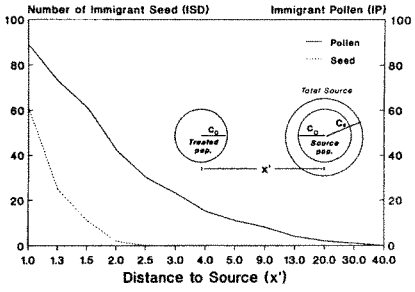


Figure 4. Pollen and seed dispersal as a function of distance (in units of treated population diameter) to a source population.

$$Usb_t = Ssb_t - Tsb_t \quad (2.8)$$

Rsb_t, Ssb_t, and Usb_t are the proportions of R phenotype (**aa** genotype), S phenotype, **Aa** genotype, and **AA** genotype, respectively, in the seedbank of the current generation. Tsb_{t-1} is the proportion of the heterozygous (**Aa**) genotype in the seedbank during the previous generation; $Tyld_{t-1}$ is the number of seed produced per unit area by the treated population in the previous generation that were the heterozygous (**Aa**) genotype.

Seedling submodel. The number of R and S seedlings (RSDL and SSDL, respectively) in the treated population at time t is calculated as follows:

$$RSDL = R_g(RSB) \quad [3.1]$$

$$SSDL = S_g(SSB) \quad [3.2]$$

where R_g and S_g are germination rates for R and S seed, respectively.

The number of seedlings of R and S phenotype that survive to become flowering plants is regulated by seedling mortality rates for the R (R_{m2}) and S (S_{m2}) phenotypes:

$$RSDL_t = RSDL(R_{m2}) \quad [3.3]$$

$$SSDL_t = SSDL(S_{m2}) \quad [3.4]$$

The proportion of seedlings of each genotype at time t are then calculated by

$$Rsdl_t = \frac{RSDL_t}{RSDL_t + SSDL_t} \quad [3.5]$$

$$Ssdl_t = \frac{SSDL_t}{RSDL_t + SSDL_t} \quad [3.6]$$

$$Tsdl_t = \frac{Tsb_t\ (Ssdl_t)}{Ssb_t} \quad [3.7]$$

$$Usdl_t = Ssdl_t - Tsdl_t \quad [3.8]$$

The parameters are defined in Table 1.

The current model includes the influence of the herbicide at the transition from the seedling to mature plant life-history stage. The effect of the herbicide on the weed population is based on its efficacy in S populations. The herbicide efficacy (h) is equivalent to the percent control relative to an untreated control plot of a S population.

Mature plant submodel. The number of R and S mature individuals in the population (RFL and SFL, respectively) at time t is equal to the number of seedlings in the population after accounting for the effect of the herbicide and R and S seedling mortality.

$$RFL_t = RSDL_t \quad [4.1]$$

$$SFL_t = SSDL_t - h(SSDL_t) \quad [4.2]$$

The proportions of each genotype at the mature stage are calculated as follows:

$$Rfl_t = \frac{RFL_t}{RFL_t + SFL_t} \quad [4.3]$$

$$Sfl_t = \frac{SFL_t}{RFL_t + SFL_t} \quad [4.4]$$

$$Tfl_t = \frac{Tsdl_t\ (Sfl_t)}{Ssdl_t} \quad [4.5]$$

$$Ufl_t = Sfl_t - Tfl_t \quad [4.6]$$

The parameters are defined in Table 1.

Pollen immigration submodel. The same equation that is used for seed immigration (Equation 1.1) is used for predicting pollen immigration but with different coefficients (a_p and bp). The immigration submodel has been adapted to predict the total number of pollen-producing plants (IP) represented by pollen reaching the treated population (Figure 4). It, therefore, is assumed that all the plants in the source population produce the same amount of pollen and that the proportions of immigrating R and S pollen are the same as the phenotype proportions of individual plants in the outside source population.

$$IP_t = (a_p\ (x' + c_o\ )^{-bp}\ )\ (c^2\ /\ c_o^2\ ) \qquad [5.1]$$

The a_p parameter is the number of pollen-producing plants per unit area at $1–c_o$ units of distance from the source population. This value is equivalent to the total number of pollen producers in the source population which is assumed to be the number of seed produced in the source population divided by a constant. The number of seed produced in the source is assumed to be equal to that produced in the treated population of the same size. The bp parameter is the slope of a linear regression of log(Ip) on $\log(x' + c_o)$. This parameter controls the steepness of the diffusion gradient which is a function of the pollen grain mass and shape as well as air flow properties. The other parameters are described in the seed immigration submodel (Equation 1.1) and in Table 1.

Pollen producer submodel. The total number of pollen producers for the treated population that are R (RP) and S (SP) at time t are calculated as

$$RP_t = Rfl_t(RFL_t + SFL_t - IP_t) + Rof(IP_t) \qquad [6.1]$$

$$SP_t = Sfl_t(RFL_t + SFL_t - IP_t) + Sof(IP_t) \qquad [6.2]$$

The proportions of pollen producers represented by each genotype are

$$Rp_t = \frac{RP_t}{RP_t + SP_t} \qquad [6.3]$$

$$Sp_t = \frac{SP_t}{RP_t + SP_t} \qquad [6.4]$$

$$Tp_t = \frac{Tfl_t\ (RP_t + SP_t\ ) - IP_t\ ) + Tof(Ip_t\ )}{RP_t + SP_t} \qquad [6.5]$$

$$Up_t = SP_t - Tp_t \qquad [6.6]$$

The parameters are defined in Table 1.

Inheritance submodel. The probability (p) of an individual's donating the **a** allele in a mating is based on the proportions of each genotype at the pollen production stage. The fitness of the R pollen relative to the S pollen (k_r) is included in the equation.

$$p = \frac{0.5\ Tp_t\ + k_r\ R_{pt}}{k_r\ R_{pt} + T_{pt} + U_{pt}} \qquad [7.1]$$

The basic Hardy-Weinberg model is based on the assumption that populations are infinitely large and mating is random (panmictic). In populations of defined size or breeding behavior that are not random, there is a potential for inbreeding. The Hardy-Weinberg equation may be modified by inclusion of an inbreeding coefficient (32, 38). The following equations result:

$$R_{t+1} = p^2(1–f) + p(f) \qquad [7.2]$$

$$T_{t+1} = 2(1–p)(p)(1–f) \qquad [7.3]$$

$$U_{t+1} = (1–p)^2(1–f) + (1–p)(f) \qquad [7.4]$$

$$S_{t+1} = T_{t+1} + U_{t+1}$$

$$f = \frac{1–2\ m}{4\ N_e\ m–2m+1} \qquad [7.5]$$

In this equation m is the mutation rate which is fixed in the current model at 10^{-6}, which is in the range suggested by Georghiou and Taylor (7). N_e is the effective size of the population which is related to the number of reproducing adults and is calculated as follows when there are differences in the number of male (N_{em}) and female (N_{ef}) adults:

$$N_e = \frac{1}{0.25(1/\ N_{ef} + 1/N_{em}\ )} \qquad [7.6]$$

It is assumed that the male part of a plant population (pollen grains) far exceeds the number of female ovules. Therefore, N_{em} approaches 0 and N_{ef} is approximated by the number of seed produced per unit area by the treated population. The unit area thus defines the finite population size.

The proportions of each genotype proceeding into the next generation have been determined above. To calculate the number of seed representing each genotype, the number of total plants involved in mating first must be calculated; then the number of those matings that will represent production of each phenotype (R and S) is determined.

$$TM_t = RFL_t + SFL_t \quad [7.7]$$

$$TMr_t = R_{t+1}(TM_t) \quad [7.8]$$

$$TMs_t = S_{t+1}(TM_t) \quad [7.9]$$

TM_t is the total number of mating plants in the current generation. TMr_t and TMs_t are the number of mating plants that will produce seed with the R and S phenotypes, respectively.

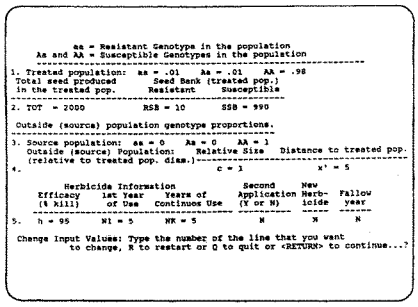
Seed yield submodel. A competition model proposed by Firbank and Watkinson (5) was adapted to predict the seed yield for individual R and S plants. Separate equations for the R and S phenotypes account for differential competitive abilities. The influence of a crop and other weed species can be included in the model in addition to intra- and inter-phenotype competition.

$$RY_t = RY_{max}[1 + a_r(RFL_t + z_{sr}SFL_t + z_{ir}N_i)]^{-br} \quad [8.1]$$

$$SY_t = SY_{max}[1 + a_s(SFL_t + z_{rs}RFL_t + z_{is}N_i)]^{-bs} \quad [8.2]$$

RY_{max} and SY_{max} are the maximum yield per plant that can be attained by the R and S phenotypes, respectively. The areas required to attain R_{max} and SY_{max} are a_r and a_s, respectively. The inter-phenotype competition coefficient which expresses the influence of the S phenotype density on the R phenotype is z_{sr}. The inter-phenotype competition coefficient that expresses the influence of the R phenotype density on the S phenotype is z_{rs}. The inter-specific competition coefficients that express the influence of the crop or other dominant weed density on the R phenotype and the S phenotype are z_{ir} and z_{is}, respectively. N_i is the density of the crop or other dominant species in the system, and br and bs are the coefficients which determine the forms of the relationship between RY_t and SY_t and the total density, respectively.

The seed yields per unit area for the R (Ryld) and S (Syld) phenotypes are calculated as follows:



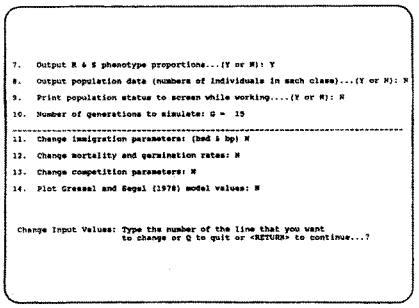


Figure 5. The second and third input screens for RSIM (the computer program version of the resistance simulation model) used for entering the initial conditions for starting a simulation and changing certain model parameter values.

$$Ryld_t = RY_t(TM_t) \quad [8.3]$$

$$Syld_t = SY_t(TM_t) \quad [8.4]$$

Ryld and Syld become the inputs to the seedbank in the next generation (t+1).

Simulations are conducted by inputting a set of initial conditions (Figure 5) and calculating in sequence equations 1.1 through 8.4. The computer program version of the resistance simulation model (RSIM) pro-

duces two types of output: a) Proportions of the R and S phenotype once per generation at the flowering stage before reproduction and b) numbers of individuals at each life-history stage for each generation.

MODEL BEHAVIOR ANALYSIS

Sensitivity and elasticity analysis (18, 20) on the complete simulation model identified two sets of life-history processes that are important for understanding and managing the dynamics of herbicide resistance: a) processes that influence fitness of the R phenotype relative to the S phenotype and crop species and b) processes that contribute to gene flow in space and time.

Fitness. Fitness describes the evolutionary advantage of a phenotype, which is based on its survival and reproductive success (2, 31). Relative fitness of R and S phenotypes has important consequences for the management of resistance. Reduced fitness in the R type (1, 14) infers that R plants will be replaced by S individuals over time after herbicide use is abandoned. Alternatively, if the fitness of the R type is not less than the S type (35), resistance should decline slowly, if at all. Fitness also will be influenced by the presence of other species. (i.e., crop or other weeds) in the system, especially if they are strong competitors. These premises have not been examined experimentally, although the alternatives lead to very different tactics for managing resistance (9).

Gene flow. Gene flow describes the processes that influence the maintenance of a particular genotype in a population. Gene flow processes directly alter the frequencies of R and S alleles in plant populations (16). Immigration of pollen and seed introduce genes into a population, while inbreeding and genetic drift result from limited gene flow. Seed dormancy conserves genes within a plant population. Seed bank dynamics include these gene flow processes, as well as seed survivorship (a fitness process).

Pollen and seed from outside populations are involved in two important management scenarios: a) the spread of resistance over the landscape and b) the use of S-genotype sources (e.g., fence rows, untreated rows, fields, addition of seed) to prevent or slow the evolution of resistance. Attempts to manage herbicide resistance are dominated by tactics to use other herbicides to remove R plants from populations that have developed resistance. Our model simulations suggest that manipulation of S-type gene flow is an alternative for resistance management. Such tactics could be more cost effective than control measures that only reduce R-type plants in already resistant fields.

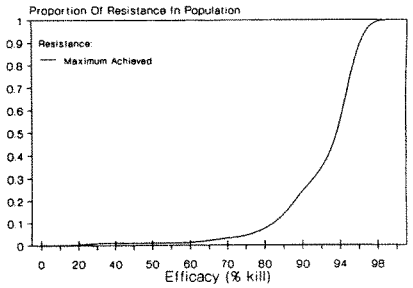


Figure 6. The influence of herbicide efficacy on the maximum level of resistance achieved in a weed population that had 5 continuous years of herbicide applications.

MANAGEMENT SCENARIOS

Simulations. The model was used to assess the influence of gene flow and fitness processes on the evolution of resistance in a weed population. Each of these assessments has management implications. In each analysis, all the parameters except for one were held constant. All the simulations were initiated with selected proportions of each genotype in the treated weed population and an adjacent (source for immigration) population of the same species. Herbicide application begins at Year 5 and is continued through Year 9 in the simulations. All references to the herbicide in the first three scenarios assume that there was a single herbicide in the system and that resistance to that herbicide is a single-gene, homozygous-recessive trait.

The relative fitness of the R and S phenotypes were arbitrarily set equal except in their relative competitive abilities with the crop (R = 1 = S = 1 and R = 0.7 that of the crop, S = 0.8 that of the crop) and their abilities to pollinate and fertilize (R = 0.9 that of S). The crop density was arbitrarily fixed at 200 plants m^{-2}. The following discussion illustrates four scenarios where model simulations were used to explore gene flow and fitness processes and their management implications.

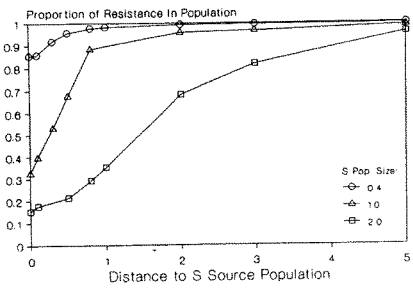


Figure 7. The influence of the size (relative to the treated population) and distance (in units of treated population diameter) to (edge of source to edge of treated) a 100% susceptible source population on the level of resistance achieved after 5 continuous years of herbicide applications.

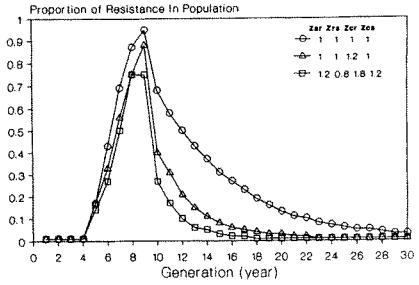


Figure 8. The influence of relative competitive abilities of resistant and susceptible phenotypes in the presence of the crop on evolution of and recovery from resistance (Equations 8.1 and 8.2).

Scenario 1. The influence of herbicide efficacy (h in Equation 4.2) on the evolution of resistance was explored (Figure 6). The simulations were initiated with no resistance in the treated populations, but resistance was introduced in each generation (year) by immigrant pollen from an adjacent (source) population. The model is designed to remove (kill) a proportion of the S individuals equivalent to the efficacy. The maximum level of resistance achieved in the treated population increased sharply when efficacy was about 80%.

The response to efficacy suggested from the simulations has important management implications. Reducing efficacy by intentionally leaving skips in the herbicide application would provide for enough healthy S individuals in the population to reduce the levels of resistance through fitness and gene flow processes. Susceptible individuals also may escape treatment naturally by following a different phenology. The potential for establishing an efficacy threshold to maintain a low proportion of resistance in a weed population is apparent. Competition and economic thresholds have been identified in many weed/crop systems (4) which indicate that high efficacy is often associated with "cosmetic" weed control rather than direct economic gain. Therefore, reducing efficacy to discourage the evolution of resistance may not reduce crop yields.

Scenario 2. This scenario examines the potential for immigrating S pollen and seed to decrease the role of evolution of resistance (Figure 7). The initial conditions for the simulations assumed 1% resistance already in the weed population followed by an increase to 90% resistance at the end of 5 continuous years of herbicide use. The influence of the size of a S source population (relative to the size of the treated population) and distance (in units of treated population diameter) to an outside S source of the weed was assessed for its ability to influence R levels in the treated population.

The simulations indicated that source areas equal to or larger than the treated population can decrease the maximum level of resistance (Figure 7). The management tactic implied by these simulations is to leave untreated adjacent rows or to maintain S populations of the weed dispersed through the treated population within a distance of one treated-population diameter.

Scenario 3. This scenario addresses the influence of competition on the evolution of and recovery from resistance (Figure 8). Competitive abilities of the R and S phenotypes relative to each other and the crop (Equations 8.1 and 8.2) were varied systematically in a set of simulations. Relative competitive ability had little influence on the rate of resistance evolution. The levels of resistance in the population over the first 3 yr of herbicide use did not differ in the simulations. However, the maximum level of resistance after 5 continuous years of herbicide use was highest (95%) when the R and S phenotypes and the crop were assumed to have equal competitive abilities. The maximum level of resistance was reduced to 85% when the R phenotype was assumed to be less competitive than both the crop and the S phenotype of the weed.

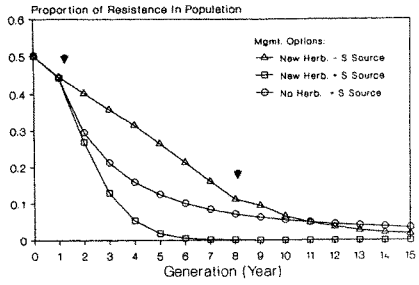


Figure 9. The use of a new herbicide (one that has 85% efficacy on both R and S individuals) and an S source population for managing recovery from herbicide resistance in a weed population. Arrows indicate the beginning and ending of continuous new herbicide applications.

The model simulations indicate that the most significant influence of relative competitive ability on resistance dynamics occurs in the recovery period following suspension of herbicide use (Figure 8). Three years after stopping herbicide use, 30% resistance remained in the population where competitive abilities were equal for the R and S phenotypes and the crop. The proportion of R plants was lower in the recovery period when the relative competitive ability of the R phenotype was decreased relative to the crop and the S phenotype.

The management tactic implied from manipulation of relative competitive abilities is to use or rotate to a crop with a greater competitive ability than the R phenotype. Manipulating competitive pressure by increasing the crop density is an equivalent management option. Changing crop densities had little influence on early evolution and maximum levels of resistance; however, critical crop densities were identified which maximized the rate of recovery to a susceptible weed population following the suspension of herbicide use.

Scenario 4. The model was used to assess management options for recovery after resistance is recognized in a weed population. The simulations were started with 50% resistance in the population. A new herbicide with 85% efficacy on R and S phenotypes was introduced at Year 1 and continued for 8 yr, then all herbicide application was suspended (Figure 9). The simulations indicated that the presence of an adjacent (source) population of S individuals decreased the time for recovery from resistance. Using a new herbicide without a source of immigrant S pollen or seed was not as effective at decreasing the level of R population as was an adjacent population without the use of a new herbicide.

The management implications suggested by these simulations further supports the potential of managing resistance by creating a source of the S phenotype to augment the effect of a new herbicide which will control both R and S weeds.

SUMMARY

The biological complexity and management implications of herbicide resistance can be explored with accurate simulation models that include pertinent biological processes. Gene flow and fitness were identified as important processes influencing resistance dynamics. These processes deserve further experiments to determine their potential for manipulation and management of resistance.

The potential management of resistance suggested by this model represents some alternative strategies and tactics with respect to other attempts to study herbicide resistance. These tactics include methods to decrease the R phenotype and to manipulate the S phenotype of the weed population. Each approach is reasonable, although greatest success should result from multiple integrated tactics for manipulating both R- and S-type weeds in a population.

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Weed Control in Dicamba-Resistant Soybeans

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Abstract

Field experiments were conducted in 11 states to evaluate broadleaf weed management programs in dicamba-resistant soybeans which involved the use of preemergence and postemergence dicamba. Preemergence (PRE) dicamba at 0.25 lb ae/acre provided less than 60% control of smooth pigweed, giant ragweed, velvetleaf, palmer amaranth, waterhemp, and morningglory spp., but 97% control of common lambsquarters and horseweed at 3 weeks after treatment (WAT). Preemergence flumioxazin plus chlorimuron or sulfentrazone plus cloransulam provided 66 to 100% control of these weeds. Use of dicamba postemergence (POST) improved uniformity of control of velvetleaf, smooth pigweed, morningglory, and glyphosate-susceptible waterhemp. However, combining dicamba at 0.25 lb/acre with glyphosate resulted in 30% to 65% greater control of glyphosate-resistant palmer amaranth, glyphosate-resistant common waterhemp, glyphosate-resistant horseweed, and glyphosate-resistant giant ragweed compared to sequentially applied glyphosate.

Introduction

Glyphosate-resistant soybean was commercialized in 1996 and as of 2007, 91% of soybean hectares in the United States were genetically engineered, herbicide-resistant varieties (9). Soybean producers have changed management practices during this time, relying more on conservation and no-tillage practices and use of glyphosate for weed control (10). Use of glyphosate in soybean production from 1995, the year prior to the introduction of glyphosate-resistant soybean when it was used as a burndown herbicide before planting, to 2006, the 10th year of use as a preplant or postemergence herbicide, in soybean increased by ten-fold in the United States (8) at the exclusion of other herbicide modes of action (10). As a result, several agronomically important broadleaf weeds have evolved resistance to glyphosate in the United States including: giant ragweed (*Ambrosia trifida*), common ragweed (*Ambrosia artemisiifolia*), waterhemp (*Amaranthus rudis*), palmer amaranth (*Amaranthus palmeri*), horseweed (*Conyza canadensis*) (4). Other species that are difficult to control with glyphosate include morningglory species (*Ipomoea* spp.), common

lambsquarters (*Chenopodium album*), and dandelion (*Taraxacum officinale*). The aforementioned weed species have been identified by growers in several recent surveys as being the most difficult to manage in current soybean production systems (3,5,6).

Although, glyphosate-resistant corn was introduced in 1997, many other herbicides in addition to glyphosate are used for postemergence weed control. Among those are plant growth regulators such as 2,4-D and dicamba. Dicamba has been used for broadleaf weed control in corn for several decades. Dicamba provides effective control of most of the common dicot weeds found in corn production (7) and to date, there are no weeds commonly found in corn production that have evolved resistance to dicamba (4). Dicamba-resistant soybean is currently being developed to assist farmers in controlling glyphosate-resistant and hard-to-control broadleaf weeds. The dicamba tolerance trait (2) will be stacked with glyphosate resistance and will provide the option of using dicamba preemergence or postemergence in soybean for weed control. There is little research published on dicamba use as a preplant burndown herbicide applied within 14 days of soybean planting, as a soil residual herbicide in soybean, or as a postemergence tankmix partner with glyphosate for control of problematic weed species often faced by farmers in the United States.

The objective of this research was to evaluate control of several problematic annual broadleaf weeds commonly found in soybean production in the United States with dicamba and dicamba + glyphosate weed control programs. Treatment programs consisted of preemergence or preplant application timings alone and followed by single or sequential postemergence applications.

Evaluating Weed Management Programs in Dicamba-Resistant Soybeans

Field experiments were conducted in Georgia, Kentucky, and Missouri in 2007 and in Georgia, Illinois, Indiana, Kansas, Kentucky, Missouri, Nebraska, North Carolina, Ohio, South Dakota, and Tennessee 2008 and 2009. Locations, soil types, and predominate broadleaf weeds at each site are shown in Table 1. Standard field research techniques were used to establish the experiments and apply preplant/preemergence and postemergence treatments. Treatments were applied with backpack sprayers at carrier volumes ranging from 15 to 20 gal/acre (GPA). Preemergence/preplant treatments were applied within 4 days before or after planting at 20 out of 23 site-years. Early postemergence (EPOST), postemergence, and late postemergence (LPOST) treatments were applied on weeds 3 to 5, 3 to 8, and 8 to 16 inches in height, respectively.

Two separate research trials were conducted. The first trial, hereafter referred to as the "non-glyphosate trial" was conducted in Indiana and Ohio in 2008 and 2009 (4 site years). Treatments evaluated in this protocol are listed in Table 2. The second trial, hereafter referred to as the "glyphosate trial," was conducted in all other states in 2007, 2008, and 2009 (19 site years) and treatments are shown in Table 3. The main difference between the treatments in the two trials is the fact that no glyphosate was applied postemergence with treatments 2 through 10 in the non-glyphosate trial. The preemergence residual herbicide used in the glyphosate trial was sulfentrazone plus cloransulam and the one used in the non-glyphosate trial was flumioxazin plus chlorimuron.

Table 1. Year, location, soil characteristics, tillage system, planting dates, and herbicide application dates for dicamba-resistant soybean field trials.

Year	Location	Soil class	Tillage	Planting date	Herbicide application dates				Weeds
					Preplant or pre-emergence (PRE)	Early post-emergence (EPOST) 3-5 inch weeds	Mid post-emergence (MPOST) 3-8 inch weeds	Late post-emergence (LPOST) 8-16 inch weeds	
2007	Fayette Co., KY	Silty clay loam	Conven-tional	Jun 18	Jun 18	Jul 9	Jul 13	Aug 3	Velvetleaf, smooth pigweed, giant ragweed, morningglory species.
2007	Platte Co., MO	Silty clay loam	Min	Jun 6	Jun 8	Jul 5	Jul 6	Jul 26	Glyphosate-resistant common waterhemp
2007	Macon Co., GA	Sandy loam	None	Jun 22	Jun 22	Jul 13	Jul 16	Aug 1	Glyphosate-resistant Palmer amaranth
2008	Fayette Co., KY	Silty clay loam	Conven-tional	Jun 2	Jun 2	Jun 19	Jun 27	Jul 25	Velvetleaf, smooth pigweed
2008	Wayne Co., NC	Loamy sand	Conven-tional	May 9	May 13	May 30	Jun 5	Jun 25	Glyphosate-resistant Palmer amaranth
2008	St. Clair Co., IL	Silty loam	Min	Jun 18	Jun 18	Jul 4	Jul 11	Jul 25	Velvetleaf, common waterhemp, morningglory species
2008	Brown Co., IL	Clay loam	None	Jun 18	Jun 20	Jul 16	Jul 23	Aug 1	Glyphosate-resistant common waterhemp
2008	Riley Co., KS	Silty loam	Conven-tional	May 15	May 15	Jun 9	Jun 17	Jul 4	Velvetleaf, Palmer amaranth, morning-glory, ivyleaf morningglory
2008	Callaway Co., MO	Silty clay loam	Conven-tional	May 29	May 5	Jun 24	Jun 26	Jul 15	Glyphosate-resistant common waterhemp
2008	Gibson Co., TN	Silty clay loam	None	Jun 2	Jun 3	Jun 23	Jun 30	Jul 14	Smooth pigweed, pitted morning-glory, glyphosate-resistant horseweed
2008	Brookings Co., SD	Clay loam	Conven-tional	May 28	May 28	Jun 20	Jul 15	Aug 8	Wild buckwheat
2008	Clark Co., OH	Silty clay loam	Min	May 25	May 25	Jun 17	Jun24	Jul17	Glyphosate-resistant giant ragweed, recdroot pigweed, velvetleaf
2008	Tippe-canoe Co., IN	Silt loam	Conven-tional	May 22	May 22	Jun 17	Jul 2	Jul 2	Common lambs-quarter, giant ragweed, velvetleaf

(continued)

Table 1 (continued).

Year	Location	Soil class	Tillage	Planting date	Herbicide application dates				Weeds
					Preplant or pre-emergence (PRE)	Early post-emergence (EPOST) 3-5 inch weeds	Mid post-emergence (MPOST) 3-8 inch weeds	Late post-emergence (LPOST) 8-16 inch weeds	
2009	Wayne Co., NC	Loamy sand	None	May 20	May 20	Jun 3	Jun 11	Jun 22	Glyphosate-resistant Palmer amaranth
2009	Jackson Co., IL	Fine, sandy loam	None	May 19	May 4	May 29	Jun 1	Jun 20	Glyphosate-resistant horseweed, common waterhemp
2009	Fayette Co., KY	Silty loam	Conven-tional	May 20	May 20	Jun 5	Jun 22	Jul 20	Smooth pigweed
2009	Brown Co., IL	Clay loam	None	May 22	May 22	Jun 22	Jun 29	Jul 14	Glyphosate-resistant common waterhemp
2009	Riley Co., KS	Silty clay loam	None	Jun 8	Jun 8	Jun 26	Jul 1	Jul 22	Palmer amaranth, giant ragweed
2009	Saunders Co., NE	Loamy sand	None	May 21	May 23	Jun 13	Jun 13	Jul 8	Common waterhemp, glyphosate-resistant horseweed
2009	Brookings, Co., SD	Clay loam	Conven-tional	May 22	May 21	Jun 23	Jul 2	Jul 10	Wild buckwheat
2009	Callaway Co., MO	Silty clay loam	None	Jun 30	Jun 30	Jul 16	Jul 16	Aug 18	Glyphosate-resistant common waterhemp
2009	Pickaway Co., OH	Silty clay loam	Min	May 5	May 5	Jun 2	Jun 16	Jun 30	Common lambs-quarter, glyphosate resistant giant ragweed
2009	Tippe-canoe Co., IN	Silt loam	Conven-tional	Jun 9	Jun 9	Jun 23	Jun 30	Jul 16	Lambsquarter, giant ragweed, redroot pigweed

Table 2. Core treatments in the non-glyphosate trial which was conducted in Indiana and Ohio in 2008 and 2009 .

Treatment number	Herbicide	Active ingredient	Formulation	Rate	Application timing
1	Roundup PowerMax N-Pak AMS Roundup PowerMax N-Pak AMS	glyphosate ammonium sulfate glyphosate ammonium sulfate	4.5 lb ae/gal 100% 4.5 lb ae/gal 100%	0.75 lb ae/acre 5 %v/v 0.75 lb ae/acre 5 %v/v	EPOST EPOST LPOST LPOST
2	Clarity Clarity	dicamba dicamba	4 lb ae/gal 4 lb ae/gal	0.25 lb ae/acre 0.25 lb ae/acre	EPOST LPOST
3	Clarity Clarity	dicamba dicamba	4 lb ae/gal 4 lb ae/gal	0.25 lb ae/acre 0.25 lb ae/acre	POST LPOST
4	Clarity Clarity	dicamba dicamba	4 lb ae/gal 4 lb ae/gal	0.125 lb ae/acre 0.25 lb ae/acre	EPOST LPOST
5	Clarity Clarity	dicamba dicamba	4 lb ae/gal 4 lb ae/gal	0.125 lb ae/acre 0.25 lb ae/acre	POST LPOST
6	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	PREPLANT/ PREEMERGENCE
7	Clarity Clarity	dicamba dicamba	4 lb ae/gal 4 lb ae/gal	0.25 lb ae/acre 0.25 lb ae/acre	PREPLANT/ PREEMERGENCE POST
8	Clarity Clarity Clarity	dicamba dicamba dicamba	4 lb ae/gal 4 lb ae/gal 4 lb ae/gal	0.25 lb ae/acre 0.25 lb ae/acre 0.25 lb ae/acre	PREPLANT/ PREEMERGENCE POST LPOST
9	Clarity Clarity	dicamba dicamba	4 lb ae/gal 4 lb ae/gal	0.25 lb ae/acre 1.5 lb ae/acre	PRE LPOST
10	Valor SX Classic Clarity	flumioxazin chlorimuron-ethyl dicamba	51% 25% 4 lb ae/gal	0.056 lb ai/acre 0.019 lb ai/acre 0.25 lb ae/acre	PREPLANT/ PREEMERGENCE POST

Table 3. Core treatments in the glyphosate trial which was conducted in Georgia, Illinois, Kansas, Kentucky, Missouri, Nebraska, North Carolina, South Dakota, and Tennessee.

Treatment number	Herbicide	Active ingredient	Formulation	Rate	Application timing
1	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
2	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	EPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	EPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	EPOST
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	LPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
3	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	LPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
4	Clarity	dicamba	4 lb ae/gal	0.125 lb ae/acre	EPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	EPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	EPOST
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	LPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
5	Clarity	dicamba	4 lb ae/gal	0.125 lb ae/acre	EPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	EPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	EPOST
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	LPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
6	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	PREPLANT/ PREEMERGENCE
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
7	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	PREPLANT/ PREEMERGENCE
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
8	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	PREPLANT/ PREEMERGENCE
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Clarity	dicamba	4 lb ae/gal 4.5	0.25 lb ae/acre	LPOST
	Roundup PowerMax	glyphosate	lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
9	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	PREPLANT/ PREEMERGENCE
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Clarity	dicamba	4 lb ae/gal	1.5 lb ae/acre	LPOST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	1.5 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST
10	Authority First DF	sulfentrazone + cloransulam-methyl	70%	0.141 lb ai/acre	PREPLANT/ PREEMERGENCE
	Clarity	dicamba	4 lb ae/gal	0.25 lb ae/acre	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	POST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	POST
	Roundup PowerMax	glyphosate	4.5 lb ae/gal	0.75 lb ae/acre	LPOST
	N-Pak AMS	ammonium sulfate	100%	5 %v/v	LPOST

Visual evaluations of weed control were collected at 3 weeks after the PRE residual treatment and 3 to 5 weeks after the LPOST treatment on a 0 to 100 scale, with 0 = no control and 100 = control or death of all plants in the plot. Crop response and yield to the herbicide treatments were not collected for this research as the soybean cultivars used were not of commercial quality. Years were treated as a random variable and data were subject to analysis of variance using Proc Mixed in SAS. Data are presented as box and whisker plots and means are separated with Fisher's Protected LSD at the 0.05 level of significance.

Residual Control of Broadleaf Weeds with Soil-Applied Dicamba

Soil activity of dicamba at 0.25 lbs ae/acre was variable depending on the target weed species. In the non-glyphosate trial, flumioxazin + chlorimuron resulted in 70% control of giant ragweed compared to less than 10% with dicamba (Fig. 1). However, control of common lambsquarters was 98% with dicamba, compared to 100% control with flumioxazin + chlorimuron. In the glyphosate trials, common lambsquarters control with dicamba PRE was excellent and similar to sulfentrazone + chloransulam (Fig. 3). In addition, PRE activity of dicamba resulted in greater than 90% control of horseweed across numerous states (Fig. 3). However, for a majority of the troublesome broadleaf weeds in soybean, residual activity of dicamba compared to sulfentrazone + chloransulam was unacceptable. For velvetleaf, smooth pigweed, Palmer amaranth, common waterhemp, giant ragweed, and morningglory, dicamba activity was less than 60% control (Fig. 3). Comparatively, sulfentrazone + cloransulam controlled velvetleaf 94%, smooth pigweed 90%, palmer amaranth 85%, common waterhemp 82%, giant ragweed 95%, and morningglory spp. 80%. These results indicate that soil-applied dicamba at 0.25 lb ae/acre is effective in suppressing horseweed and common lambsquarters, but is much less effective than common industry standards at suppressing other widespread, problematic weeds evaluated in this research.

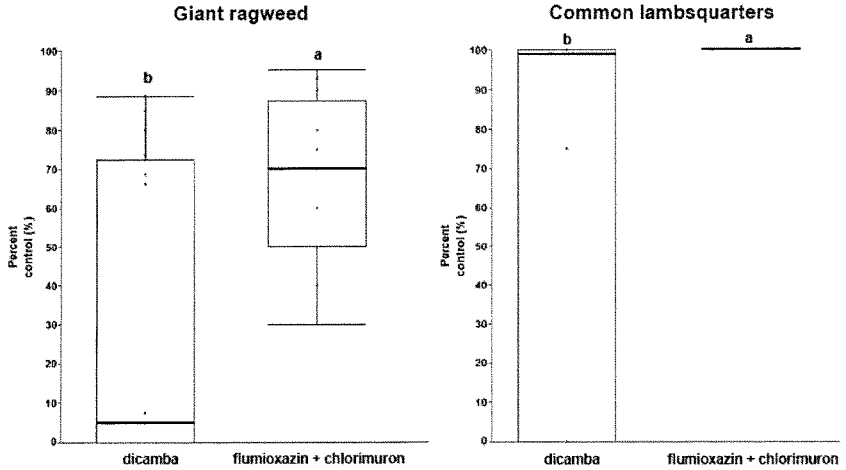
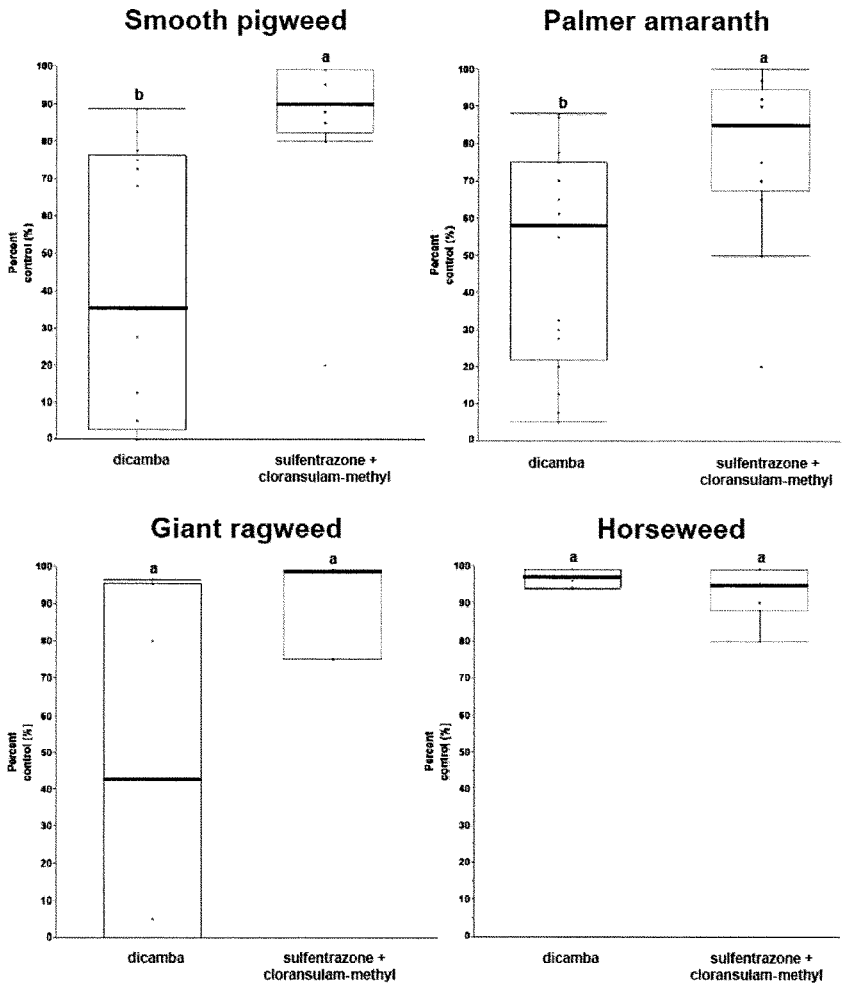


Fig. 1. Box and whisker plots of percent control with preplant dicamba (0.25 lb ae/acre) or flumioxazin (0.056 lb ai/acre) + chlorimuron (0.019 lb ai/acre) at 3 WAT in the non-glyphosate trial conducted in Indiana and Ohio. Horizontal line in the box denotes the mean value, upper edge (hinge) denotes 75th percentile, lower hinge denotes 25th percentile, vertical lines extend to the highest and lowest values. Means followed by the same letters are not different at $P = 0.05$.


Smooth pigweed
Palmer amaranth
Giant ragweed
Horseweed
Percent control (%)
a
b
dicamba
sulfentrazone + cloransulam-methyl

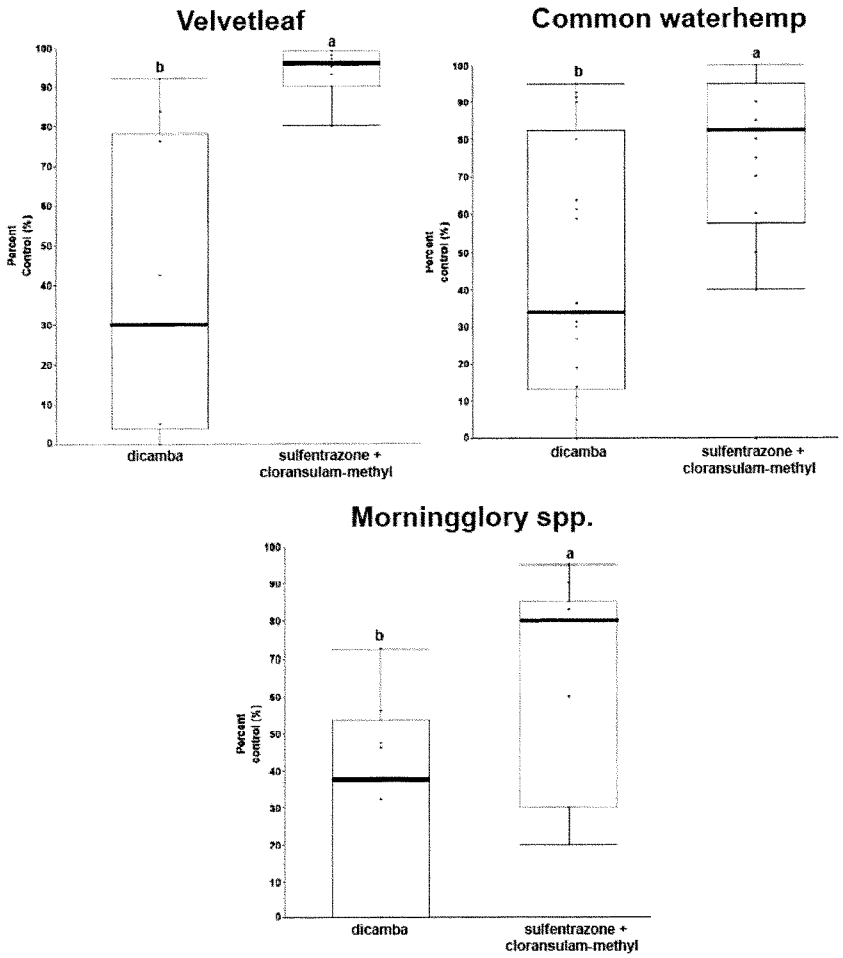
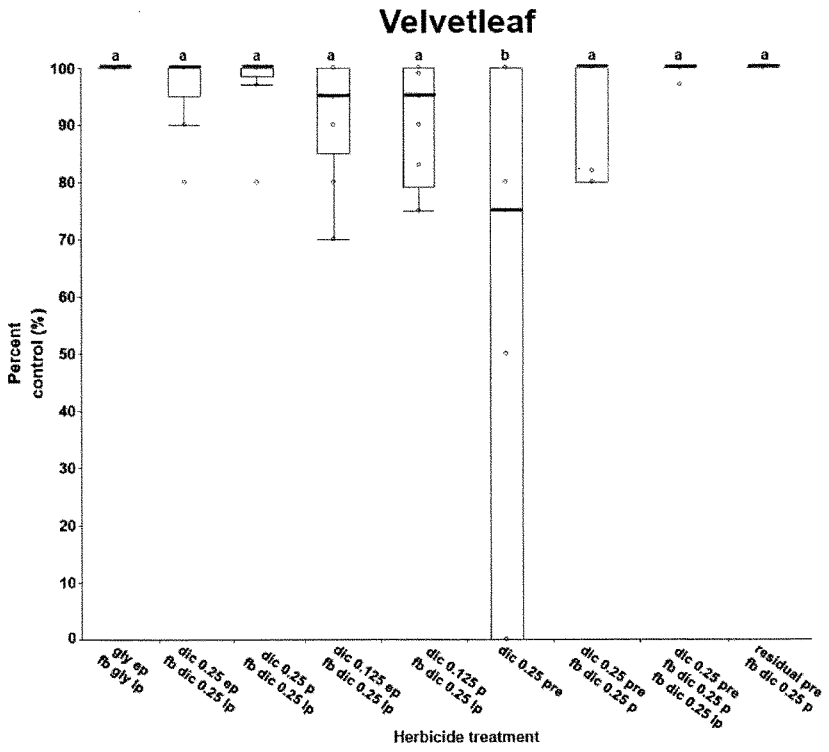
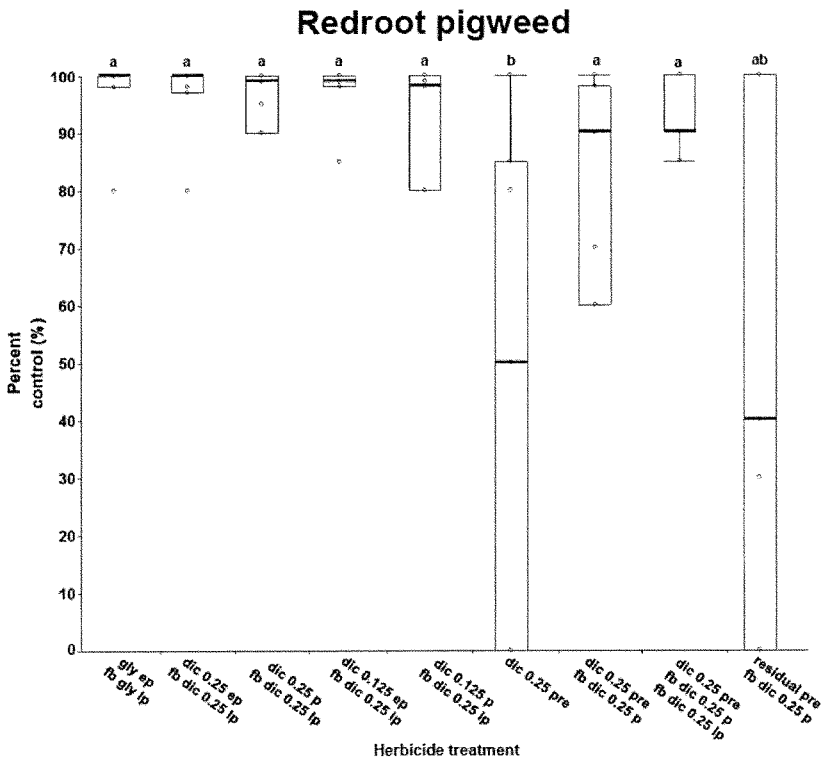
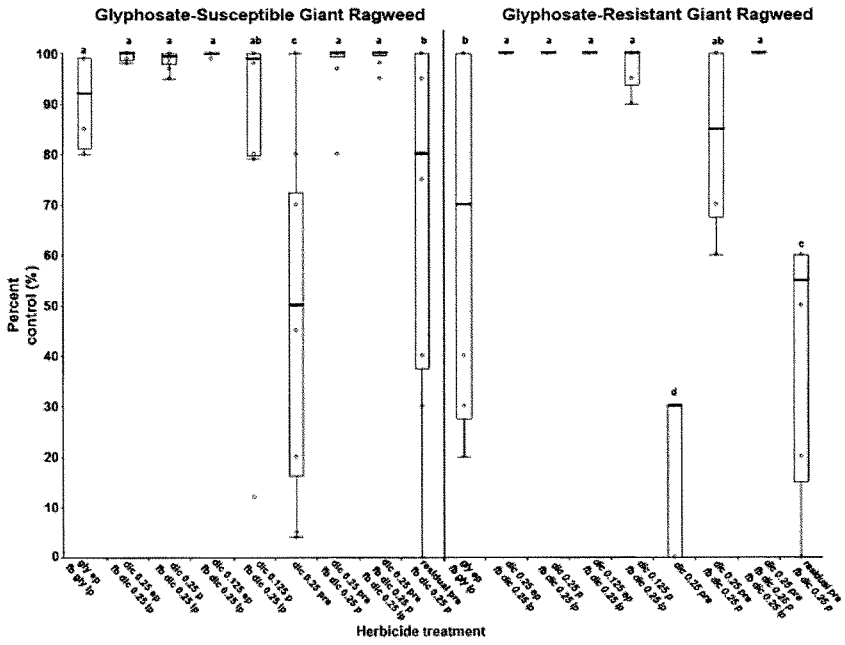


Fig. 2. Box and whisker plots of percent control with preplant dicamba (0.25 lb ae/acre) or sulfentrazone + cloransulam-methyl (0.141 lb ai/acre) at 3 WAT in the glyphosate trial conducted in Georgia, Illinois, Kansas, Kentucky, Missouri, Nebraska, North Carolina, South Dakota, and Tennessee. Horizontal line in the box denotes the mean value, upper edge (hinge) denotes 75th percentile, lower hinge denotes 25th percentile, vertical lines extend to the highest and lowest values. Means followed by same letters are not different at $P = 0.05$.


Velvetleaf
a
a
a
a
a
b
a
a
a
100
90
80
70
60
50
40
30
20
10
0
Percent control (%)
gly ep fb gly lp
dic 0.25 ep fb dic 0.25 lp
dic 0.25 p fb dic 0.25 lp
dic 0.125 ep fb dic 0.25 lp
dic 0.125 p fb dic 0.25 lp
dic 0.25 pre
dic 0.25 pre fb dic 0.25 p
dic 0.25 pre fb dic 0.25 p fb dic 0.25 lp
residual pre fb dic 0.25 p
Herbicide treatment


Redroot pigweed
a
a
a
a
a
b
a
a
ab
100
90
80
70
60
50
40
30
20
10
0
Percent control (%)
gly ep fb gly lp
dic 0.25 ep fb dic 0.25 lp
dic 0.25 p fb dic 0.25 lp
dic 0.125 ep fb dic 0.25 lp
dic 0.125 p fb dic 0.25 lp
dic 0.25 pre
dic 0.25 pre fb dic 0.25 p
dic 0.25 pre fb dic 0.25 p fb dic 0.25 lp
residual pre fb dic 0.25 p
Herbicide treatment


Glyphosate-Susceptible Giant Ragweed
Glyphosate-Resistant Giant Ragweed
Percent control (%)
Herbicide treatment

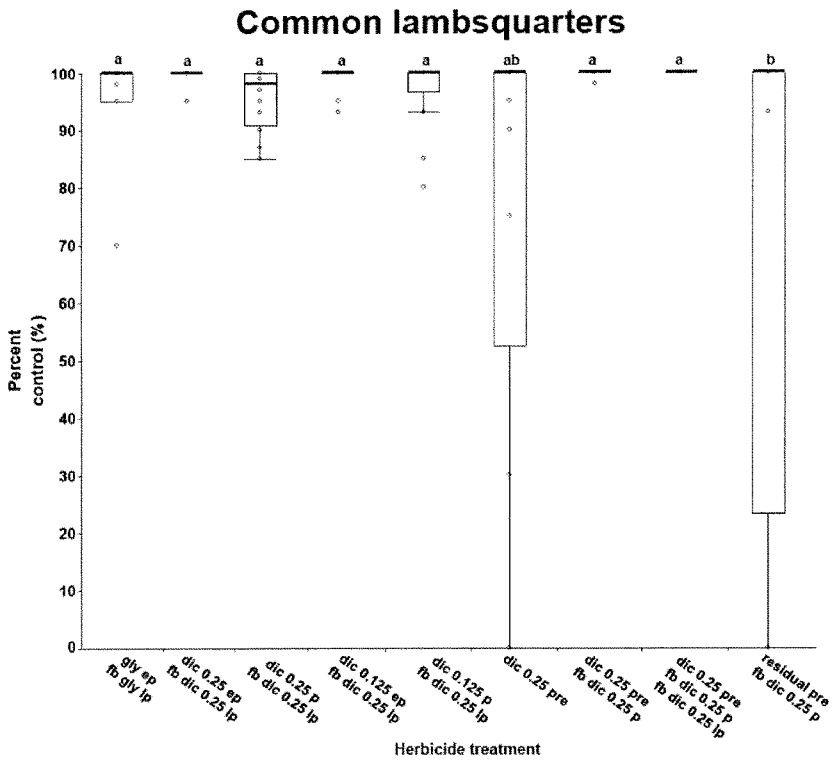


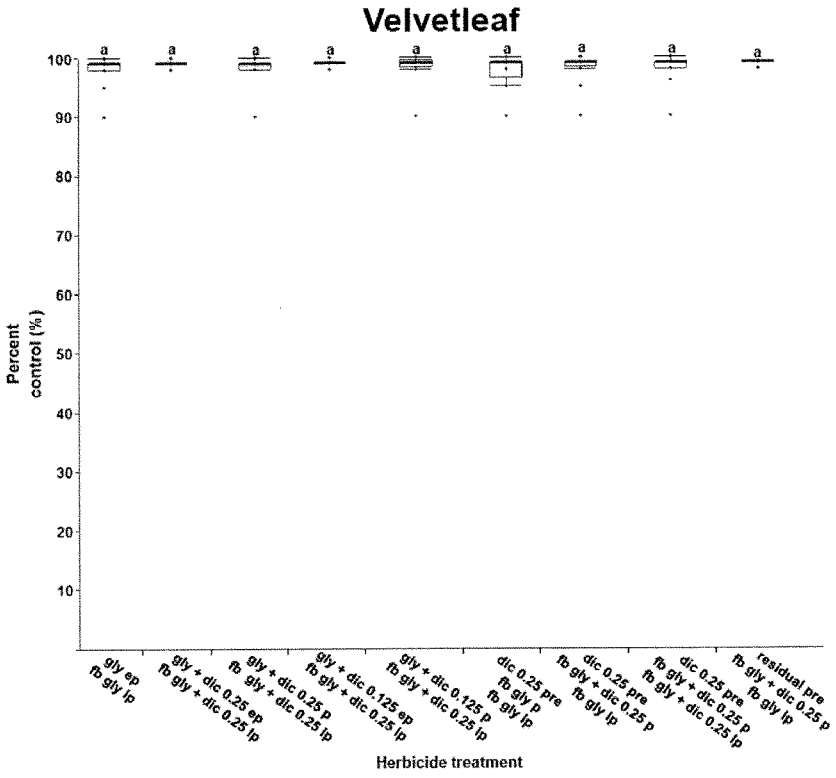
Fig. 3. Box and whisker plots of percent control with various postemergence treatments at 3 to 5 weeks after the last post treatment in the non-glyphosate trial conducted in Indiana and Ohio. Abbreviations: gly = glyphosate; dic = dicamba; pre = preplant; ep = early post; p = post; lp = late post; fb = followed by. Horizontal line in the box denotes the mean value, upper edge (hinge) denotes 75th percentile, lower hinge denotes 25th percentile, vertical lines extend to the highest and lowest values. Means followed by the same letter are not different at $P = 0.05$.

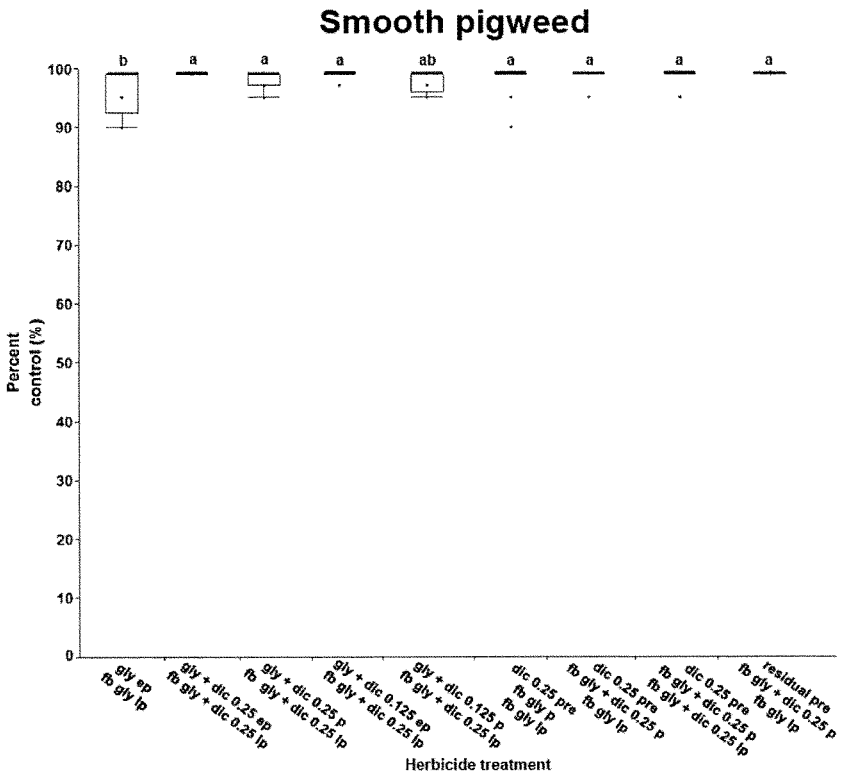
Control of Broadleaf Weeds with Postemergence Dicamba Alone Compared to Glyphosate Alone

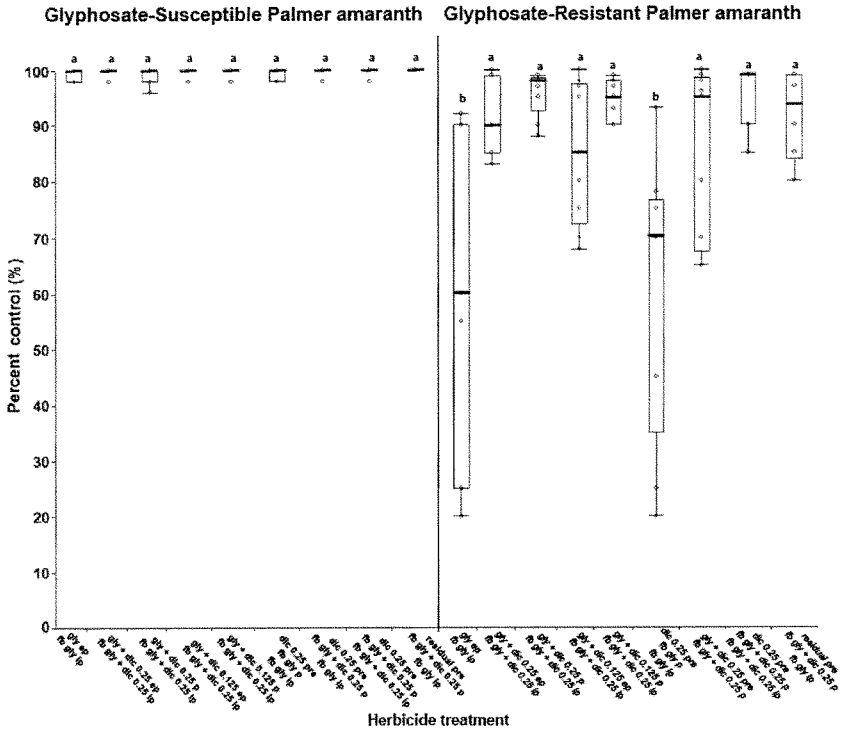
In the non-glyphosate trial, control of velvetleaf with dicamba was rate dependent (Fig. 3). Treatments which included dicamba at 0.125 lb ae/acre resulted in up to 5% lower control than treatments which included 0.25 lb ae/acre in the initial postemergence treatment, and more velvetleaf plants survived with the lower POST rates of dicamba. Redroot pigweed and common lambsquarters control was not as rate dependent as velvetleaf, but control was timing dependent. EPOST followed by LPOST sequential treatments provided slightly greater control (5 to 10%) than POST followed by LPOST sequential treatments, irrespective of the dicamba rate. Control of glyphosate-resistant giant ragweed was only 70% with glyphosate alone compared to 92% control of the glyphosate-susceptible biotype (Fig. 3). Application of sequential treatments of dicamba POST, irregardless of rate or timing, resulted in complete control of both biotypes of giant ragweed.

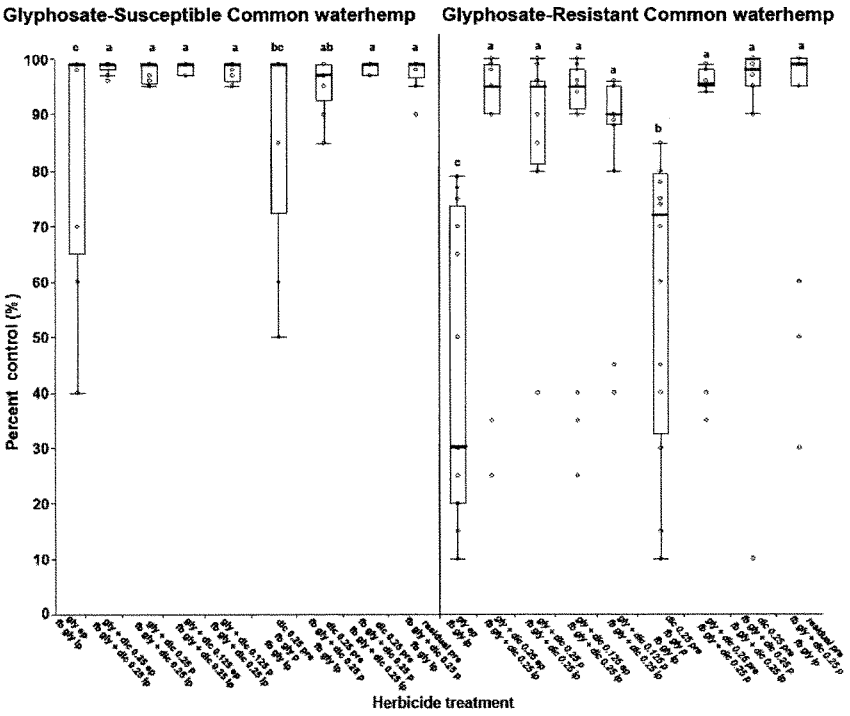
Control of Broadleaf Weeds with Glyphosate + Dicamba vs. Glyphosate Alone

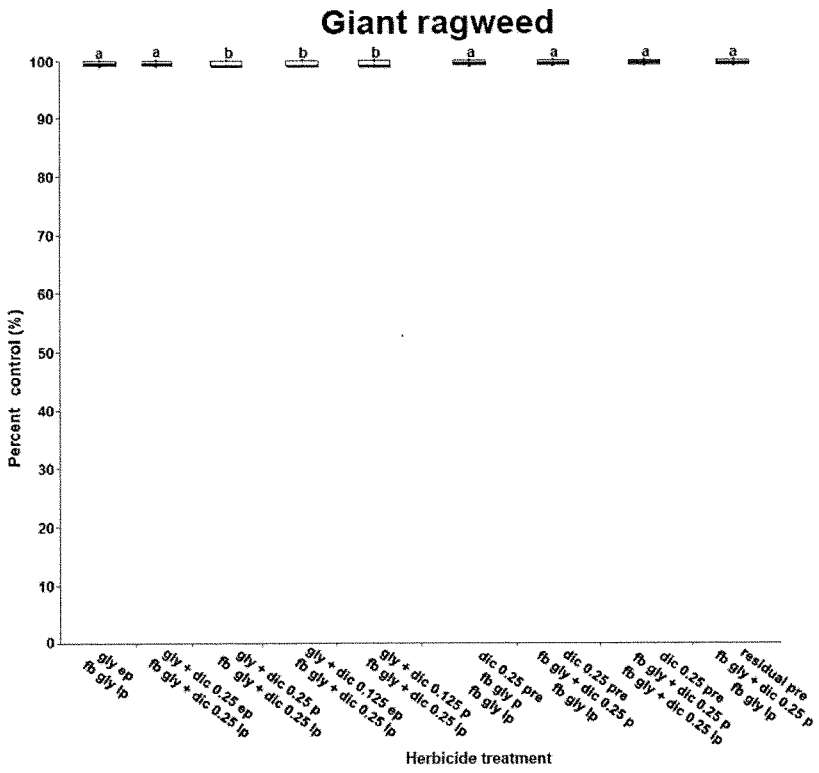
In the glyphosate trial, control of velvetleaf, smooth pigweed, glyphosate-susceptible Palmer amaranth and waterhemp, giant ragweed, and wild buckwheat was 95% or higher with all treatments (Fig. 4). Control of smooth pigweed was timing dependent and treatments which include EPOST application timings provided slightly less variable control than treatments which were applied POST or LPOST, and the addition of dicamba improved control over glyphosate alone. At sites with glyphosate-resistant plants, inclusion of dicamba in the POST treatment greatly improved weed control versus glyphosate alone. For Palmer amaranth, waterhemp, and horseweed, control increased from 60 to 100%, 30 to 95%, and 85 to 98%, respectively. Common waterhemp control was variable with glyphosate alone at both glyphosate-resistant and -susceptible sites. This would indicate that despite the absence of glyphosate-resistant waterhemp at many sites, dicamba improved the consistency of control. Treatments which included glyphosate applied postemergence without dicamba provided lower levels of weed control than treatments which included POST dicamba. Horseweed control was higher and less variable in treatments that included dicamba or flumioxazin, sulfentrazone, chlorimuron, or cloransulam applied preemergence than with treatments that included only postemergence glyphosate or glyphosate + dicamba. With morningglory, treatments which included glyphosate applied postemergence without dicamba resulted in 90 to 93% control. This increased to 98 to 99% control when dicamba was included POST.

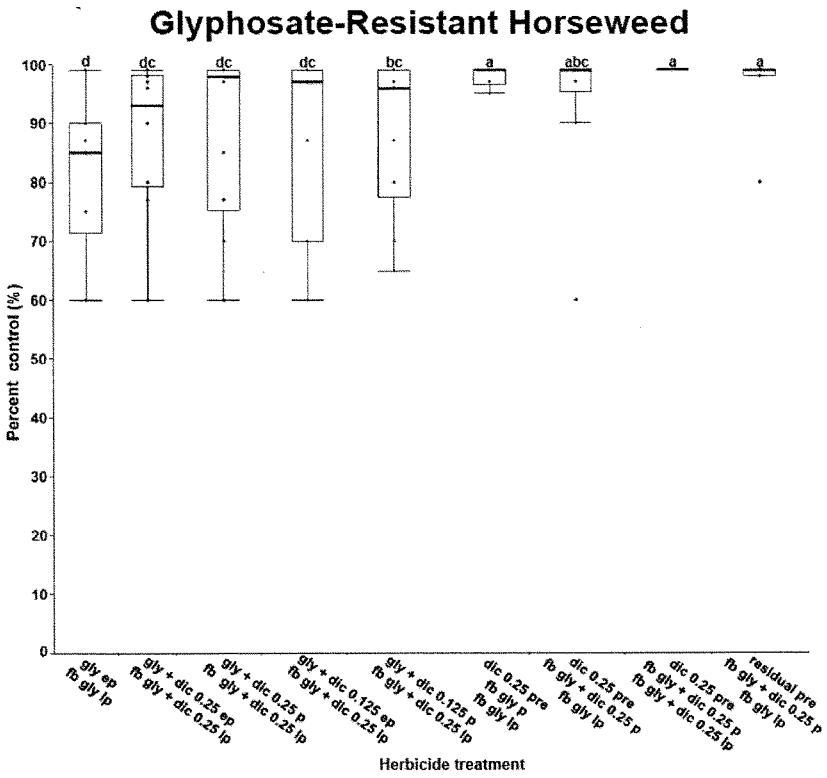

Velvetleaf
Percent control (%)
100
90
80
70
60
50
40
30
20
10
a
gly ep fb gly lp
gly + dic 0.25 ep fb gly + dic 0.25 lp
gly + dic 0.25 p fb gly + dic 0.25 lp
gly + dic 0.125 ep fb gly + dic 0.25 lp
gly + dic 0.125 p fb gly + dic 0.25 lp
dic 0.25 pre fb gly lp
dic 0.25 pre fb gly + dic 0.25 p
dic 0.25 pre fb gly + dic 0.25 lp
residual pre fb gly + dic 0.25 p fb gly lp
Herbicide treatment

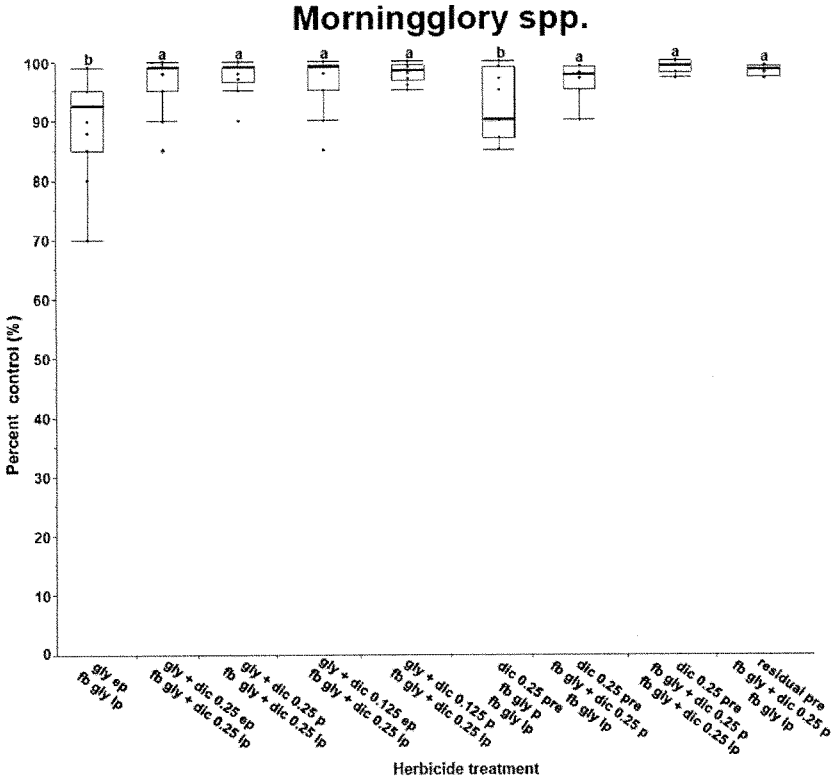

Smooth pigweed
b
a
a
a
ab
a
a
a
a
100
90
80
70
60
50
40
30
20
10
0
Percent control (%)
gly ep fb gly lp
gly + dic 0.25 ep fb gly + dic 0.25 lp
gly + dic 0.25 p fb gly + dic 0.25 lp
gly + dic 0.125 ep fb gly + dic 0.25 lp
gly + dic 0.125 p fb gly + dic 0.25 lp
dic 0.25 pre fb gly p fb gly lp
dic 0.25 pre fb gly + dic 0.25 p fb gly lp
dic 0.25 pre fb gly + dic 0.25 p fb gly + dic 0.25 lp
residual pre fb gly + dic 0.25 p fb gly lp
Herbicide treatment


Glyphosate-Susceptible Palmer amaranth
Glyphosate-Resistant Palmer amaranth
Percent control (%)
Herbicide treatment


Glyphosate-Susceptible Common waterhemp
Glyphosate-Resistant Common waterhemp
Percent control (%)
Herbicide treatment


Giant ragweed
a
a
b
b
b
a
a
a
a
100
90
80
70
60
50
40
30
20
10
0
Percent control (%)
gly ep
fb gly lp
gly + dic 0.25 ep
fb gly + dic 0.25 lp
gly + dic 0.25 p
fb gly + dic 0.25 lp
gly + dic 0.125 ep
fb gly + dic 0.25 lp
gly + dic 0.125 p
fb gly + dic 0.25 lp
dic 0.25 pre
fb gly p
fb gly lp
dic 0.25 pre
fb gly + dic 0.25 p
fb gly lp
dic 0.25 pre
fb gly + dic 0.25 p
fb gly + dic 0.25 lp
residual pre
fb gly + dic 0.25 p
fb gly lp
Herbicide treatment


Glyphosate-Resistant Horseweed
Percent control (%)
100
90
80
70
60
50
40
30
20
10
0
d
dc
dc
dc
bc
a
abc
a
a
gly ep
fb gly lp
gly + dic 0.25 ep
fb gly + dic 0.25 lp
gly + dic 0.25 p
fb gly + dic 0.25 lp
gly + dic 0.125 ep
fb gly + dic 0.25 lp
gly + dic 0.125 p
fb gly + dic 0.25 lp
dic 0.25 pre
fb gly p
fb gly lp
dic 0.25 pre
fb gly + dic 0.25 p
fb gly lp
dic 0.25 pre
fb gly + dic 0.25 p
fb gly + dic 0.25 lp
residual pre
fb gly + dic 0.25 p
fb gly lp
Herbicide treatment


Morningglory spp.
Percent control (%)
100
90
80
70
60
50
40
30
20
10
0
b
a
a
a
a
b
a
a
a
gly ep
fb gly lp
gly + dic 0.25 ep
fb gly + dic 0.25 lp
gly + dic 0.25 p
fb gly + dic 0.25 lp
gly + dic 0.125 ep
fb gly + dic 0.25 lp
gly + dic 0.125 p
fb gly + dic 0.25 lp
dic 0.25 pre
fb gly p
fb gly lp
dic 0.25 pre
fb gly + dic 0.25 p
fb gly lp
dic 0.25 pre
fb gly + dic 0.25 p
fb gly + dic 0.25 lp
residual pre
fb gly + dic 0.25 p
fb gly lp
Herbicide treatment

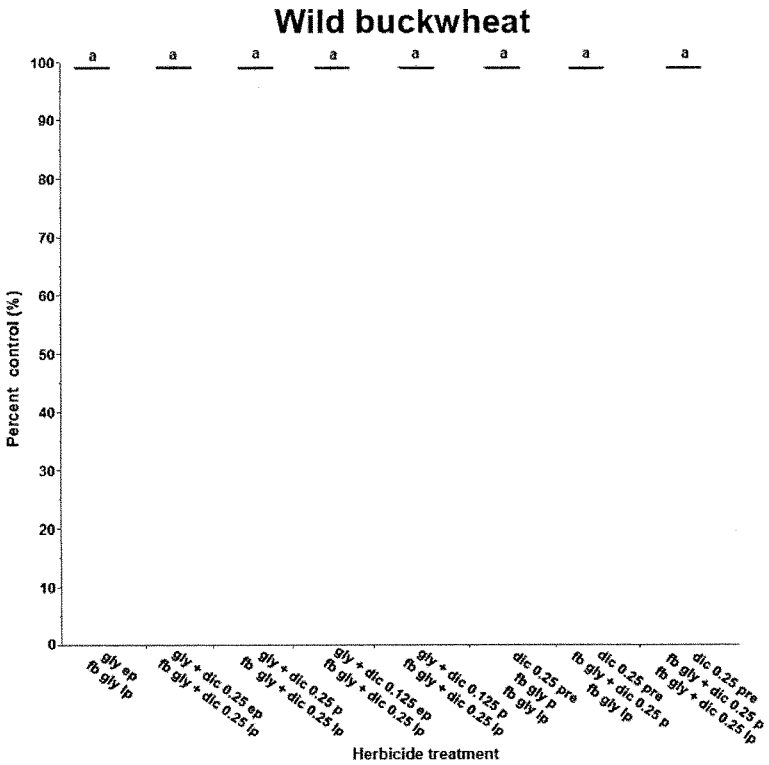


Fig. 4. Box and whisker plots of percent control with various postemergence treatments at 3 to 5 weeks after the last postemergence treatment in the glyphosate trial conducted in Georgia, Illinois, Kansas, Kentucky, Missouri, Nebraska, North Carolina, South Dakota, and Tennessee. Abbreviations: gly = glyphosate; dic = dicamba; pre = preplant; ep = early post; p = post; lp = late post; fb = followed by. Horizontal line in the box denotes the mean value, upper edge (hinge) denotes 75th percentile, lower hinge denotes 25th percentile, vertical lines extend to the highest and lowest values. Means followed by the same letter are not different at $P = 0.05$.

Integration of new herbicide-tolerance traits such as dicamba results in the addition of novel modes of herbicide action and improves the consistency of POST broadleaf control programs versus glyphosate alone. Dicamba can also reduce the selection pressure for glyphosate-resistant weeds, preserving the technology of glyphosate-tolerant soybeans. In this research, residual activity of dicamba appears sufficient for early season control of horseweed and common lambsquarters. POST dicamba improved the control of the glyphosate-susceptible weeds evaluated, but improved control was most notable for the glyphosate-resistant weeds horseweed, giant ragweed, Palmer amaranth, and common waterhemp. Dicamba also improved the consistency of control of morningglory.

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EVOLUTION IN ACTION: GLYPHOSATE-RESISTANT WEEDS THREATEN WORLD CROPS

Stephen B Powles, WA Herbicide Resistance Initiative, School of Plant Biology, University of Western Australia spowles@plants.uwa.edu.au – outlines the development of glyphosate resistant weeds and the weed control problems that are associated with it

Keywords: glyphosate, herbicide, resistance, GM crops, evolution, sustainability

Introduction

Glyphosate is by far the world's most widely used and important herbicide because it is efficacious, economical and environmentally benign (Dill *et al.*, 2008; Duke & Powles, 2008). Glyphosate dominates for non-selective weed control in agricultural ecosystems, especially to remove weeds between rows in established perennial tree, nut, vine crops and before seeding of annual crops. Globally, glyphosate is also the non-selective herbicide of choice in urban and industrial areas, national parks and other amenity areas. In these use patterns, there have been few instances of weeds evolving glyphosate resistance. While there are documented cases of glyphosate-resistant weed evolution in several countries (Table 1, reviewed by Powles, 2008) given the long term glyphosate usage, experience establishes that plants cannot easily evolve resistance to this herbicide.

The common factor in those examples (Table 1) where glyphosate-resistant weeds have evolved is very persistent glyphosate usage with little or no diversity in weed control practices. Unsurprisingly, glyphosate resistance has evolved most often in the resistance-prone genera *Conyza* and *Lolium*. It is important to recognise, however, that glyphosate continues to be effective globally in its traditional use patterns for non-selective weed control where there is sufficient diversity in control practices and not an extreme over-reliance on glyphosate. However, as discussed below, this situation has dramatically changed now that glyphosate has become a selective herbicide in transgenic crops.

Table 1. Global reports of evolved glyphosate-resistant weeds resulting from use of glyphosate as a non-selective herbicide (see Heap 2008, Powles 2008).

Species	Countries
Conyza spp.	Brazil, China, Spain, Israel, South Africa, USA
Lolium spp.	Australia, Brazil, Chile, France, South Africa, Spain, USA
Echinochloa colona	Australia
Eleusine indica	Malaysia, Taiwan
Parthenium hysterophorus	Colombia
Plantago lanceolata	South Africa

Glyphosate as a selective herbicide in transgenic glyphosate resistant crops

From 1996 onwards, a landmark development occurred with the commercialisation of transgenic (genetic modification obtained through gene manipulation using recombinant DNA technology) crops. By far the most important development has been crops endowed with a bacterial gene conferring resistance to glyphosate (Dill *et al.*, 2008). In transgenic glyphosate-resistant crops (hereinafter referred to as GR crops), glyphosate is used as a selective herbicide to remove weeds without crop damage, providing easy, economical, efficient weed control along with other agronomic advantages such as earlier seeding and reduced or zero tillage. GR crops are a spectacular commercial success (in those countries in which GM crops can be grown) with 95% of the more than 100 million hectares of currently grown transgenic crops being GR crops (Figure 1; James, 2006). In the Americas, the speed and extent of GR crop adoption has been phenomenal. GR soybean, cotton and maize dominate USA cropping. In 2006 GR soybean comprised 90%, cotton 91% and maize 60% of the entire USA plantings of these crops (Figure 2, Dill *et al.*, 2008). In southern USA cropping regions, GR soybean, cotton and maize are rotated on the same fields. In central and northern USA cropping regions, GR soybeans are almost universal and are often in rotation with GR maize.

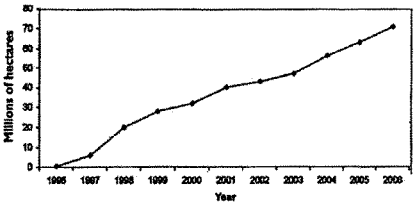


Figure 1: **Global glyphosate resistant crops.**

In Argentina, the adoption of GR crops is even more complete with almost the entire soybean crop being GR (Figure 3). GR crops are also being rapidly adopted in Brazil. The widespread adoption of GR crops and consequent high glyphosate usage (Figures 1-3) is understandable, as glyphosate is easy to use, economical and provides excellent weed control. GR crops all contribute to

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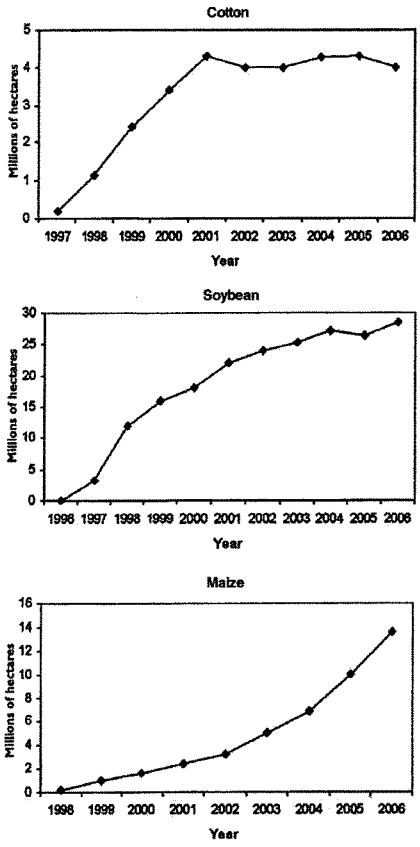


Figure 2: **Adoption of glyphosate-resistant crops in USA.**

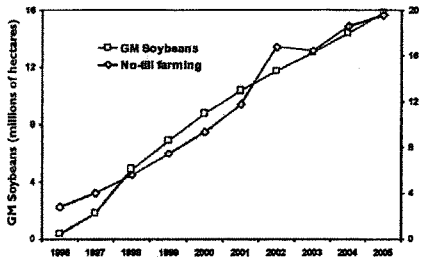


Figure 3: **Adoption of GR soybean and no-till seeding in Argentina.**

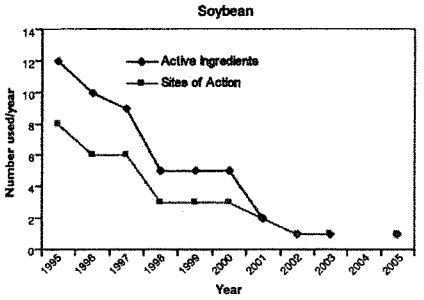


Figure 4: **Number of different herbicide active ingredients and herbicide sites of action used on at least 10% of hectares from 1995 to 2005 in soybean in the USA.**

widespread, high level adoption and therefore unprecedented, often exclusive, use of glyphosate over very large areas. While economically rational for growers and industry (Gianessi, 2005), from an evolutionary perspective the "glyphosate landscape" is an ideal environment in which any weedy plants that can survive glyphosate can thrive. This is especially so because the adoption of GR crops and intensive glyphosate usage often results in the cessation of use of alternative herbicides (Shaner, 2000) and/or tillage, and, therefore, there is no diversity in weed control practices. This further adds to the selection pressure for plants that can survive glyphosate. The adoption of GR soybean and glyphosate in the USA removed alternative herbicide diversity, resulting in almost complete reliance on glyphosate (Figure 4). This is also the case in Argentina and Brazil.

It must be emphasised that glyphosate used repeatedly and persistently post-emergent in GR crops across vast areas is a more intense evolutionary selection pressure for resistance than that which prevails for most traditional glyphosate uses (outlined in the Introduction). In a GR crop, any weed plants that survive glyphosate are likely to flower, pollinate and produce seed. Thus, in GR crops grown on the same fields for several years those weed species that have some level of natural tolerance to glyphosate can come to prominence in GR cropping systems (comprehensively reviewed by Owen, 2008). As well as these widely-occurring weed spectrum shifts, intense glyphosate use in GR crops grown persistently in the same fields/landscapes is a strong selection for resistance to evolve in previously glyphosate susceptible weed species (Powles, 2003). Evolved glyphosate-resistant weeds are a major risk for the continued success of GR crops.

Table 2. Evolved glyphosate-resistant weeds in transgenic glyphosate-resistant crops (see Heap 2008, Powles 2008)

Species	Country
Ambrosia artemisiifolia	USA
Ambrosia trifida	USA
Amaranthus palmeri	USA
Amaranthus tuberculatus	USA
Amaranthus rudis	USA
Conyza spp.	Brazil, USA
Lolium spp.	Brazil, USA
Sorghum halepense	Argentina, USA
Euphorbia heterophylla	Brazil

Table 2 lists the currently documented cases of evolved glyphosate-resistant weeds from usage of glyphosate as a selective herbicide in GR crops.

It is in GR crop areas in the USA and Argentina that glyphosate-resistant weed evolution is most threatening. Since the first report of glyphosate-resistant *Conyza canadensis* in a US GR soybean field in 2001, there are now at least three million hectares of USA GR crops infested with glyphosate-resistant *Conyza*. Even more worrisome are glyphosate-resistant populations of far more economically damaging weed species (Table 2). In some mid-western USA states there are now several known glyphosate-resistant populations of the very vigorous, highly competitive and economically damaging weeds *Ambrosia artemisiifolia* and *Ambrosia trifida*, as well as *Amaranthus rudis* and *Amaranthus tuberculatus*. In the southern cotton-growing states, there are many reports of glyphosate-resistant populations of *Amaranthus palmeri*, a very damaging weed of cotton crops. Evolution of glyphosate resistance in *Ambrosia* and *Amaranthus* populations is a looming threat to GR crop productivity and sustainability in the USA.

As in the USA, GR soybean has been massively adopted in Argentina. Almost the entire 16 million hectare Argentine soybean crop is GR, and nearly all of this is in no-till production systems with little diversity in weed control, and almost exclusive reliance on glyphosate. Additionally, GR maize is being adopted at a rapid rate. Therefore, the selection pressure is intense for evolution of glyphosate-resistant weeds. So far, the very damaging weed *Sorghum halepense* has evolved glyphosate resistance across a significant area of the GR soybean crop in the Salta province (Vila-Aiub *et al.*, 2008). Brazil did not commercialise GR crops until well after Argentina, the USA and Canada, with GR crop adoption occurring mainly since 2005. However, rapid adoption of GR soybean, maize and cotton is now underway. Thus far, glyphosate-resistant populations of *Conyza* and *Euphorbia heterophylla* have evolved in Brazilian GR soybean areas (Table 2). Paraguay and Uruguay are also adopting GR crops. Given the dominance of GR crops in soybean, cotton and maize agro-ecosystems in major cropping regions of North and South America, more species will inevitably evolve glyphosate resistance.

Canada: One example of sustainable use of a GR crop

It is instructive to contrast the situation in Canada with that in the USA and Argentina. In the western Canadian grainbelt provinces (Alberta, Manitoba, Saskatchewan), canola is the only GR crop present. In this agro-ecosystem, non-GR wheat and barley dominate, with canola as an important rotational crop. Additionally, not all the canola grown is GR: in 2007, of the six million hectares of canola in Canada, only 70% was GR. Canadian growers also have transgenic glufosinate-resistant canola, and mutagenesis-derived imidazolinone herbicide resistant canola. Therefore, there is the option for diversity in canola type and herbicide use. Also, it is important to recognise that as canola is a rotational crop, it is grown on a particular cropping field only every third or fourth year. As the rotational cereal and any other crops are not GR, it is thus likely that a GR crop is grown on a particular field only infrequently. Clearly, the glyphosate selection intensity on weed species in this Canadian canola-cereal cropping agro-ecosystem is much less than with GR crops in the USA or Argentina. Unsurprisingly, there are currently no known cases of evolved glyphosate-resistant weeds in Canada. This is undoubtedly due to the diversity (as it refers to herbicide use) evident in the Canadian cropping system, relative to that in the GR soybean-maize-cotton agro-ecosystems of the USA. Thus, GR canola should remain sustainable in Canada if this diversity is maintained. There are important lessons to be learnt for other parts of the world, from this sustainable use of a GR crop in Canada.

Conclusion

A major lesson evident from more than three decades of non-selective glyphosate use to control billions of plants worldwide is that where diversity in weed management systems is maintained, then weed control by glyphosate can be sustainable. Glyphosate is a remarkably robust herbicide from a resistance evolution viewpoint. However, as reviewed above, it is clear that where there is very intense glyphosate selection without diversity, glyphosate-resistant weed populations will evolve. Particularly, the evolution of glyphosate-resistant weed populations is a major threat in areas where transgenic glyphosate-resistant crops dominate the landscape, and in which glyphosate selection is intense and without diversity. As glyphosate usage continues to be intensive in these areas (Foresman & Glasgow, 2008), it is likely that glyphosate-resistant weeds will become a major problem. There is a strong likelihood that resistance evolution will eliminate glyphosate as a weed management option in these important crop regions. This being so, the re-introduction and/or maintenance of diversity in these agro-ecosystems is essential. What specifically constitutes "diversity" will vary according to region, ecosystem, enterprises, economics and many other factors. However, diversity will involve herbicide rotations/sequences, mixtures

of robust rates of herbicides with different modes of action, and use of non-herbicide weed control tools. Such diversity must be introduced now in the GR cropping areas of the USA, Argentina and Brazil. Mixtures of glyphosate with effective doses of different herbicides are already being adopted, and transgenic crops with additional herbicide-resistance genes are in development (Behrens *et al.*, 2007, Green *et al.*, 2008, Sammons *et al.*, 2007). Alternative herbicides and integration with non-herbicidal weed control tools will be required.

For those regions of the world that have not yet adopted GR crops and/or intensive glyphosate usage, there are lessons to be learnt from the GR crop experience in the Americas. By avoiding intense glyphosate reliance and through maintenance of diversity, the longevity of this precious herbicide resource and of excellent GR crop technologies can be sustained for future harvests. Glyphosate is essential for present and future world food production, and action to secure its sustainability should be a global imperative.

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Herbicide-Resistant Crops: Utilities and Limitations for Herbicide-Resistant Weed Management†

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Since 1996, genetically modified herbicide-resistant (HR) crops, particularly glyphosate-resistant (GR) crops, have transformed the tactics that corn, soybean, and cotton growers use to manage weeds. The use of GR crops continues to grow, but weeds are adapting to the common practice of using only glyphosate to control weeds. Growers using only a single mode of action to manage weeds need to change to a more diverse array of herbicidal, mechanical, and cultural practices to maintain the effectiveness of glyphosate. Unfortunately, the introduction of GR crops and the high initial efficacy of glyphosate often lead to a decline in the use of other herbicide options and less investment by industry to discover new herbicide active ingredients. With some exceptions, most growers can still manage their weed problems with currently available selective and HR crop-enabled herbicides. However, current crop management systems are in jeopardy given the pace at which weed populations are evolving glyphosate resistance. New HR crop technologies will expand the utility of currently available herbicides and enable new interim solutions for growers to manage HR weeds, but will not replace the long-term need to diversify weed management tactics and discover herbicides with new modes of action. This paper reviews the strengths and weaknesses of anticipated weed management options and the best management practices that growers need to implement in HR crops to maximize the long-term benefits of current technologies and reduce weed shifts to difficult-to-control and HR weeds.

KEYWORDS: Corn; *Zea mays*; cotton; *Gossypium hirsutum*; soybean; *Glycine max*; crop; herbicide; resistance; tolerance; weed management

INTRODUCTION

Herbicide-resistant (HR) crops, particularly glyphosate-resistant (GR) crops, have transformed the way many growers manage weeds. However, after three decades and billions of dollars invested in research, only a few transgenic herbicide traits are commercially available (*1*−*3*). Two transgenes code for a glyphosate-insensitive 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS; EC 2.5.1.19), the *cp4 epsps* gene from *Agrobacterium tumefaciens* strain CP4 and the mutated *zm-2mepsps* from corn (*Zea mays* L.), and three transgenes code for metabolic inactivation. One gene from *Ochrobactrum anthropi* strain LBAA encodes for glyphosate oxidoreductase (GOX), and two homologous genes, *pat* and *bar* from *Streptomyces viridochromogenes* and *Streptomyces hygroscopicus*, respectively, encode *N*-acetyltransferases that inactivate glufosinate. Today, HR traits are used on >80% of the estimated 134 million hectares of transgenic crops grown annually in 25 countries (*3*, *4*) with a single trait, CP4 EPSPS, being by far the most utilized (*5*).

Growers rapidly adopted the first GR crops because the technology enabled a new weed control practice with glyphosate that was effective, easy-to-use, economical, safe, and novel. The novel attribute of the gene technology was essential to get patents that protected the large investment needed to develop the technology, whereas growers touted the simplicity and convenience of the glyphosate-based crop systems (*1*−*3*). Initially, glyphosate was exceedingly effective in GR crops, and many growers relied only on glyphosate to control weeds. Some academic weed scientists were concerned about the sustainability of this approach and predicted the evolution of resistance. However, no cases of GR weeds had evolved after more than two decades of broad use in noncrop situations (*6*), and some weed scientists and growers began to think that GR weeds would never be a problem. Then the paradigm changed in 1996 with the discovery of GR rigid ryegrass (*Lolium rigidum* Gaudin) in Australia (*7*, *8*).

Today, all accept the evolution of GR weeds is threatening the continued success of GR crops and the sustainability of glyphosate. Nineteen weeds have evolved resistance to glyphosate; about half evolved in GR crops (*9*). The basis for resistance has been attributed to altered EPSPS target site (*10*), reduced translocation or cellular transport to the plastid (*11*), sequestration in the vacuole (*12*), and gene amplification (*13*). GR weeds increase the cost of weed control and diminish the benefits of glyphosate-based weed management systems. In retrospect, it was inevitable that GR weeds would evolve. Glyphosate was a victim of its own

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Table 1. Herbicide Types Commonly Used in Corn, Soybeans, and Cotton and Their Application Method, Preemergence (PRE) or Postemergence (POST), with Respect to Crop

herbicide type (group[a])	corn	soybean	cotton
glyphosate (G)	PRE and POST	PRE and POST	PRE and POST
glufosinate (H)	POST	POST	POST
ALS inhibitor (B)	PRE and POST	PRE and POST	PRE and POST
synthetic auxin (O)	PRE and POST	PRE and POST	PRE and POST
HPPD inhibitor (F2)	PRE and POST	PRE	
PPO inhibitor (E)	PRE and POST	PRE and POST	PRE and POST
ACCase inhibitor (A)		POST	POST
photosystem inhibitor (C)	PRE and POST	PRE and POST	PRE and POST
cell division inhibitor (K2)	PRE	PRE	PRE
phytoene desaturase inhibitor (F3)		PRE	

[a] Herbicides grouped according to the Herbicide Resistance Action Committee http://www.plantprotection.org/hrac.

success. No matter how effective a herbicide is, weed management programs cannot rely so heavily on one tactic or weeds will ultimately adapt and survive in large numbers.

In essence, GR crops created the "perfect storm" for weeds to evolve resistance. Growers applied glyphosate alone over vast cropping areas to control genetically variable and prolific weeds year after year. Many of these weeds had already evolved resistance to other herbicide modes of action, so there was no good herbicide alternative when these weeds subsequently evolved resistance to glyphosate (*14*). Of particular note is the case of the highly competitive and prolific Palmer amaranth (*Amaranthus palmeri* S. Wats.). The explosion of GR Palmer amaranth populations in the southeastern United States became known as the "pigweed disaster" (*15*). These GR populations are forcing growers to change their production practices and increase the costs for weed control, even to the extent of hand-weeding. Because of these shortsighted use practices, glyphosate is not as effective as it used to be and growers must supplement glyphosate with other herbicides.

Growers now need to diversify the herbicides they use to mitigate the spread of GR weeds (*16*). Unfortunately, the chemical industry has not commercialized a herbicide with a new mode of action (MOA) for over two decades (*17*). This is partly because the number of chemicals that must be tested to discover a new herbicide has increased from fewer than 1000 in 1950 to more than 500,000 today and partly because companies are investing less money to discover new herbicides as the widespread use of GR crops has reduced the market opportunity. To address the GR weed problem, the industry is now developing new herbicide resistance traits that will expand the utility of currently available herbicides. However, it is critically important to recognize that these traits represent interim solutions for current weed problems and do not replace the long-term need to discover herbicides with new modes of action and to diversify weed management tactics.

UTILITIES AND LIMITATIONS OF CURRENT HERBICIDE TECHNOLOGIES

Current Herbicide Use Practices. GR crops came at a time of great socioeconomic change in agriculture. Farm size was increasing, and the number of growers was declining; thus, growers had to become more efficient. Furthermore, weeds were rapidly evolving resistance to various herbicides, and growers perceived weed management as taking too much time. Growers wanted new weed management tactics, and GR crops enabled an economical, efficient, and simple solution. Once growers started using glyphosate, they overused it. The average rate and number of applications of glyphosate increased as its price declined, and the use of other herbicides decreased (*18*, *19*). Competitors reacted by reducing the price of their herbicides, but those alternatives could not maintain their market presence (*20*).

In retrospect, GR crops could have helped to increase the diversity of herbicides that growers used (**Table 1**). GR crops did not require that growers use only glyphosate and the added diversity of glyphosate combined with other herbicides would have mitigated the evolution of HR weeds. However, the use of tank mixtures and sequential application of different herbicides declined. In one year, from 1997 to 1998, the use of glyphosate increased 81% in parallel with the increase of GR soybeans [*Glycine max* (L.) Merr.] from 13 to 36% (*21*). The number of herbicide active ingredients used on at least 10% of the U.S. soybean area declined from 11 in 1995 to only 1, glyphosate, in 2002 (*22*). Even though the chance of weeds evolving resistance to glyphosate in a particular location is still predicted to be lower than that with other herbicides, weeds ultimately did evolve glyphosate resistance as a direct result of the lack of weed management diversification on incredibly large areas of GR crops (*23*, *24*).

Interestingly, HR weeds often do not decrease the amount of herbicide used because growers make herbicide decisions based on weed complexes, not individual species or biotypes. If a weed evolves resistance to a herbicide, that herbicide has not lost all of its value as it still controls other weeds, and growers often continue to use the herbicide in a program with another herbicide to control the resistant weed. Furthermore, growers do not "recognize" the potential for weeds to evolve resistance to glyphosate until the biotypes appear in their fields (*25*). Unfortunately, this can lead to the practice of sequentially using herbicides until they are no longer effective, which is the fastest way to evolve multiple HR weeds (*16*). A combination of herbicides, cultural, and mechanical tactics provides the greatest protection from HR weeds.

Some weed species are particularly troublesome to control and in their propensity to evolve resistance (**Table 2**). Problematic weeds in glyphosate-based production systems that have evolved genetic mutations that confer glyphosate resistance include Palmer amaranth and waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer]. Other weeds such as velvetleaf [*Abutilon theophrasti* (L.) Medik.], morningglories (*Ipomoea* spp.), Asiatic dayflower (*Commelina communis* L.), tropical spiderwort (*Commelina benghalensis* L.), and field bindweed (*Convolvulus arvensis* L.) often survive because of naturally higher tolerance. Populations of tolerant weed species increase when growers use less than full-labeled rates (*26*). Currently, at least seven GR weed species have evolved resistance to multiple herbicide MOAs, with one population of waterhemp in Illinois being resistant to four (*27*). The rapid expansion of multiple HR weed populations threatens the sustainability of current crop production systems (*16*).

The best weed management strategy is to control weeds prior to the loss of crop yield potential and proactively delay the evolution of weed resistance. Fortunately, most fields do not have GR weeds yet, and there is still time for many growers to implement diverse and proactive weed management practices (**Table 3**) (*28*).

Table 2. Summary of Key Row Crop Weeds and Herbicide Efficacy

weed species[a]		control rating (0–10) and resistance status[b,c]						
common name	scientific name	glyphosate	glufosinate	ALS inhibitors	synthetic auxins	HPPD inhibitors	PPO inhibitors	ACCase inhibitors
		Dicotyledons						
common lambsquarters	*Chenopodium album* L.	8R	8	7R	9R	9	9	0
redroot pigweed	*Amaranthus retroflexus* L.	9	8	9R	9	9	9	0
waterhemp	*Amaranthus tuberculatus* (Moq.) Sauer	9R	8	9R	8	9	9R	0
Palmer amaranth	*Amaranthus palmeri* S. Wats.	9R	8	9R	9	9	9	0
velvetleaf	*Abutilon theophrasti* Medik.	8	8	8–9	8	9	8	0
common cocklebur	*Xanthium strumarium* L.	9	9	9R	9	8	8	0
common ragweed	*Ambrosia artemisiifolia* L.	8R	9	8R	9	7	9R	0
giant ragweed	*Ambrosia trifida* L.	7–8R	8	7–8R	9	8	8	0
horseweed	*Conyza canadensis* (L.) Cronq.	7–8R	8	7R	8	8	8	0
morningglories	*Ipomoea* spp.	7	8	7	9	7	8	0
kochia	*Kochia scoparia* (L.) Schrad.	9R	8	9R	9R	7	8	0
common sunflower	*Helianthus annuus* L.	9	9	9R	9	9	8	0
		Monocotyledons						
giant foxtail	*Setaria faberi* Herrm.	9	9	8R	0	8	7	9R
green foxtail	*Setaria viridis* (L.) Beauv.	10	8	9R	0	4	5	9R
yellow foxtail	*Setaria pumila* (Poir.) Roemer & J.A. Schultes	9	8	9R	0	6	7	9
johnsongrass (rhizome)	*Sorghum halepense* (L.) Pers.	9R	6	8R	0	0	8	9R
shattercane	*Sorghum bicolor* (L.) Moench	10	9	10R	0	8	7	9R[d]
large crabgrass	*Digitaria sanguinalis* (L.) Scop.	9	8	9R	0	7	6	9R
barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	9	9	9R	0	7	6	9R
woolly cupgrass	*Eriochloa villosa* (Thunb.) Kunth.	9	9	9	0	7	5	8
fall panicum	*Panicum dichotomiflorum* Michx.	9	8	8	0	5	4	9R
Italian ryegrass	*Lolium multiflorum* L.	9R	8	8R	0	3	3	9R
feral corn	*Zea mays* L.	9R	7R	8R	0	0	6	9R[e]

[a] Weed selection determined by a market research survey of U.S. corn, soybean, and cotton growers by Gfk Kynetec, Inc., St. Louis, MO (used with permission). [b] Weed control ratings are summarized from U.S. extension guides with 0 being the lowest and 10 being the highest level of control. A rating of ≥7 indicates effective herbicide control. Weed ratings represent the highest observed for any active in that class. [c] An R next to herbicide efficacy rating indicates that this weed has developed resistance to herbicide mode of action (Heap 2010). [d] ACCase resistance has been confirmed but not listed at Heap 2010. [e] ACCase trait currently under development and anticipated to be an issue in feral corn after commercialization.

Generally, the basic management tactics are the same for both the prevention and control of HR weeds, that is, diversification of tactics to reduce selection pressure imposed by specific herbicides. The challenge is to implement these practices under prevailing economic constraints when growers are not convinced resistance management tactics will be effective or they believe industry will continue to deliver new solutions to manage weeds (*29*). Many growers are reluctant to diversify weed management because they perceive alternative tactics as being less cost-effective despite growing evidence that such tactics can improve profitability as well as mitigate resistant weed issues (*30*). More education will help overcome this perception as will the explosion of multiple HR weeds that emphatically persuades growers to diversify their weed management practices now or face serious long-term consequences.

Current Herbicide Technologies. Besides glyphosate, most current herbicides used for weed management in corn, soybean, and cotton are selective and typically used in mixtures to control a broad spectrum of weed species. The following section provides an overview of the utilities and limitations for various herbicide MOAs that have potential utility in HR crops.

Glyphosate. Glyphosate is a nonselective, broad-spectrum foliar herbicide with no soil residual activity that has been used for >30 years to manage annual, perennial, and biennial herbaceous grass, sedge, and broadleaf weeds as well as unwanted woody brush and trees. Glyphosate is labeled to control over 300 weed species. Many glyphosate formulations and salts are commercially available; the most common salts are the monopotassium and isopropylamine. The type and amount of adjuvant included in the various formulations differ greatly and strongly influence weed control. Glyphosate strongly competes with the substrate phosphoenolpyruvate (PEP) at the EPSPS enzyme-binding site in the chloroplast, resulting in the inhibition of the shikimate pathway. Products of the shikimate pathway include the essential aromatic amino acids tryptophan, tyrosine, and phenylalanine and other important plant metabolic products (*31*). The relatively slow MOA and physicochemical characteristics result in glyphosate translocation throughout the plant and accumulation at the vital growing points before phytotoxicity occurs.

Favorable physicochemical characteristics, low cost, tight soil sorption, application flexibility, low mammalian toxicity, and availability of GR crops have helped make glyphosate the most widely used herbicide in the world (*32*). A key advantage for glyphosate has been the consistent control of weeds almost without regard to size. However, the flexibility in glyphosate application timing and lack of soil residual have often resulted in growers delaying applications to help ensure that all of the weeds have emerged. Unfortunately, such delay in application means that the weeds have begun to compete with the crop and thus reduced potential yield. The increased use of mixtures with herbicides that have soil residual activity will encourage growers to make earlier glyphosate applications and increase the likelihood that a single application gives season-long control. Other commonly noted weaknesses with glyphosate are higher rates needed to control the more tolerant broadleaf weeds, antagonism by hard water and tank mixture partners, slow speed of action, and poor rainfastness.

Table 3. Assessment of Commonly Used Tactics for Herbicide-Resistant Weed Management (Adapted from Reference *28*)

tactic	benefits	risks	potential impact
herbicide rotation	reduced selection pressure, control HR weeds	lack of different MOAs, phytotoxicity, cost, limited weed spectrum of alternatives	excellent
herbicide mixtures	reduced selection pressure, improved control, broader weed spectrum	poor activity on HR weed species, increased cost; potential phytotoxicity	excellent
variable application rate and timing	better control of HR species, more efficient herbicide use	lack of herbicide residual activity, timing may be too late to protect yield potential, more applications	good to excellent
adjusted herbicide rates	better control of target species	increased target-site selection pressure with higher rates, increased nontarget site with lower rates (polygenic resistance)	poor to fair
precision herbicide application	decreased herbicide use, reduced selection pressure	increased cost of application, unavailability of weed population maps; poor understanding of weed seedbank dynamics; increased variability of control	poor
primary tillage	decreased selection pressure, consistent efficacy; depletion of weed seedbank	increased time required, increased soil erosion, increased costs, additional tactics needed	good to excellent
mechanical weed control strategies	decreases selection pressure; consistent efficacy, relatively inexpensive	increased time required, high level of management skill needed, additional tactics needed, potential for crop injury	poor to fair
crop selection/ rotation	changes agro-ecosystem, allows different herbicide tactics, reduced selection pressure	economic risk of alternative rotation crop, lack of adapted rotation crop, rotation crops similar and thus minimal impact on the weed community, herbicides, required, lack of research base, inconsistent impact on HR weed populations	fair to good
adjusted time of planting	potential improved efficacy on target weeds, reduced selection pressure	requires alternative strategies (tillage or herbicide), potential for yield loss, need for increased rotation diversity	poor to fair
adjusted seeding rate	reduced selection pressure, improved competitive ability for the crop	increased seed cost, potentially increased pest problems, increased intraspecific competition, reduced potential yields	fair
planting configuration	improved competitive ability for the crop, reduced selection pressure	unavailability of mechanical strategies, emphasis on herbicides, equipment limitations	good
cover crops, mulches, intercrop systems	improved competitive ability, reduced selection pressure, improved systems diversity, allelopathy	inconsistent effect on HR weeds, lack of understanding about systems, limited research base, potential crop yield loss, need for herbicide to manage the cover crop, lack of good cover crops	poor
seedbank management	reduced HR weed pressure, reduced selection pressure	lack of understanding about seedbank dynamics, requires aggressive tillage, emphasis on late herbicide applications, high level of management skill needed	fair to good
adjustment of nutrient use	improved competitive ability for the crop, efficient use of nutrient	lack of research base, inconsistent results, potential crop yield loss	poor

Glufosinate. Glufosinate is a nonselective, broad-spectrum foliar herbicide with no soil residual soil activity that inhibits glutamine synthetase [GS; EC 6.3.1.2], an enzyme that catalyzes the conversion of glutamate plus ammonium to glutamine as part of nitrogen metabolism (*31*). Glufosinate is faster acting and controls key broadleaf weeds such as morninglories (*Ipomoea* spp.), hemp sesbania (*Sesbania herbacea* (P. Mill.) McVaugh), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), and yellow nutsedge (*Cyperus esculentus* L.) better than glyphosate. However, glufosinate is used at higher rates and has historically been more expensive than glyphosate. Cost and more restrictive application timing relative to weed size are probably its greatest disadvantages compared to glyphosate. Because glufosinate behaves as a contact herbicide, it must be applied to smaller plants than glyphosate and is not as effective on perennials that require significant translocation for complete control. Still, glufosinate is labeled to control >120 broadleaf weeds and grasses including key GR weeds. No weeds have been formally reported as glufosinate-resistant yet (*9*).

Synthetic Auxins. Synthetic auxin herbicides act as auxin agonists by mimicking the plant growth hormone indole-3-acetic

acid (IAA), disrupting growth and development processes, and eventually causing plant death, particularly in broadleaf species (*31*). Growers have used auxin herbicides widely for over 60 years as selective herbicides in monocotyledonous crops. Auxins control a broad spectrum of broadleaf weeds, including key weeds that have evolved resistance to glyphosate. Some synthetic auxins such as dicamba have fair soil residual activity with a half-life from 7 to 21 days. Relatively few weeds have evolved resistance to auxin herbicides, which is noteworthy considering their long-term and widespread use. For example, only six weed species have evolved resistance to dicamba after 50 years of widespread use in cereal and noncrop environments (*9*).

The increased use of dicamba and other auxin herbicides in auxin-resistant crops has the potential of injuring other broadleaf crops and reducing biodiversity in field edges and nearby noncrop habitat if unmanaged (*33*). Off-target movement of auxin herbicides can occur via spray particle and vapor drift. Particle drift is more problematic than vapor drift, but growers can manage with modified application techniques, drift control adjuvants, and correct decisions as to when, where, and how to apply. Particularly troublesome for auxin herbicides would be any movement onto highly sensitive crops such as soybeans, cotton (*Gossypium hirsutum* L.), or grapes (*Vitis vinifera* L.). Interestingly, 2,4-D is safer than dicamba on soybeans and dicamba is safer than 2,4-D on cotton (*34*). As little as 0.01% of the labeled rate of dicamba can injure soybeans (*35*), and 0.001% of the labeled rate of 2,4-D butyl ester formulation can injure tomatoes (*Lycopersicon esculentum* Mill.) and lettuce (*Lactuca sativa* L.) (*36*).

Some forms of dicamba and 2,4-D are highly volatile, especially at high temperatures. For example, the acid form of dicamba is more volatile than amine salt formulations, and some amine salts are more volatile than others. Considerable research is underway to minimize volatilization with new salts and formulations. The manufacturer can also reduce potential off-target movement with application restrictions based on temperature, droplet size, humidity, and wind speed. Because of their volatility and the sensitivity of nontarget crops, growers will probably not use auxin herbicides on vast areas during warm weather as is currently done with glyphosate.

HPPD Inhibitors. The enzyme 4-hydroxyphenyl pyruvate dioxygenase [HPPD; EC 1.13.11.27] converts 4-hydroxyphenyl pyruvate to homogentisate, a key step in plastoquinone biosynthesis. This is the most recently discovered herbicide MOA, and active analogue testing continues to generate new products (*37*). Inhibition of HPPD causes bleaching symptoms on new growth by indirectly inhibiting carotenoid synthesis due to the requirement of plastoquinone as cofactor of phytoene desaturase [PDS; EC 1.14.99] (*38*). Visible injury depends on carotenoid turnover and thus is slower to appear on older tissues than young leaves (*31*). HPPD-inhibiting herbicides control a number of important weed species and may have soil residual activity, and no weeds have been formally reported to be resistant to this MOA yet. Corn is naturally tolerant to key HPPD herbicides, but soybeans and cotton are generally sensitive.

ALS Inhibitors. Herbicides that inhibit acetolactate synthase (ALS; EC 2.2.1.6), also known as acetohydroxyacid synthase (AHAS), were discovered in the mid-1970s and are still widely used (*39*, *40*). The ALS enzyme is a key step in the biosynthesis of the essential branched-chain amino acids valine, leucine, and isoleucine. ALS is a nuclear encoded enzyme that moves to the chloroplast via a transit peptide. More than 50 different ALS-inhibiting herbicides from five different chemical classes (sulfonylureas, imidazolinones, triazolopyrimidines, pyrimidinylthiobenzoates, and sulfonylamino-carbonyl-triazolinones) are commercially available. The characteristics of ALS herbicides vary in their soil residual properties, crop response, and types of weeds that are effectively controlled. ALS herbicides can provide foliar and soil residual activity on important grass and broadleaf weeds at low application rates. The tendency of weeds to evolve resistance to ALS herbicides limits their utility (*9*), and their use is now mainly in mixtures with other types of herbicides.

PPO Inhibitors. Protoporphyrinogen oxidase (PPO; EC 1.3.3.4) is an essential enzyme that catalyzes the last common step in the biosynthesis of heme and ultimately chlorophyll by the oxidation of protoporphyrinogen IX to protoporphyrin IX. PPO-inhibiting herbicides cause the accumulation of protoporphyrinogen IX, which is photoactive, and exposure to light causes the formation of singlet oxygen and other oxidative chemicals that cause rapid burning and desiccation of leaf tissue. The soil residual and fast action characteristics of PPO herbicides complement the lack of soil residual and the slow activity of glyphosate.

PPO enzyme mutations tend to reduce the enzymatic activity, which helps explain the relatively slow evolution of resistant weeds to this 40-year-old herbicide class (*41*). Companies continue to synthesize analogues and commercialize new PPO-inhibiting herbicides. For example, saflufenacil was introduced in 2010 and is labeled for use in a wide variety of crops, including corn, soybeans, and cotton (*42*). Its label describes burndown and residual control of 70 broadleaf weeds including key troublesome weeds in glyphosate-based systems such as common lambsquarters (*Chenopodium album* L.), horseweed [*Conyza canadensis* (L.) Cronq.], waterhemp, and common (*Ambrosia artemisiifolia* L.) and giant (*Ambrosia trifida* L.) ragweeds.

ACCase Inhibitors. Acetyl coenzyme A carboxylase [ACCase; EC 6.4.1.2] is the first step of fatty acid synthesis and catalyzes the adenosine triphosphate (ATP)-dependent carboxylation of malonyl-CoA to form acetyl-CoA in the cytoplasm, chloroplasts, mitochondria, and peroxisomes of cells (*43*). ACCase-inhibiting herbicides generally inhibit the ACCase activity of monocot species and not dicots. The three chemical classes of ACCase inhibitors are cyclohexanediones (DIMs) (e.g., sethoxydim), aryloxyphenoxypropionates (FOPs) (e.g., quizalofop), and phenylpyrazolines (DENs) (e.g., pinoxaden). The ability to use ACCase herbicides selectively in corn would be useful, but the tendency of weeds to evolve resistance to this herbicide class would limit its utility to being part of a weed management system (*9*).

Other Herbicide Types. Currently used selective and burndown herbicides will continue to play important roles in weed management in HR crop systems (**Table 1**). In addition to the herbicide types already discussed, photosystem II (PSII) inhibitors such as triazine and urea herbicides, lipid synthesis inhibitors such as *S*-metolachlor, and phytoene desaturase (PDS) inhibitors such as clomazone will continue to be used as crop-selective herbicides to provide soil residual activity on key weeds. Paraquat is a photosystem I (PSI) inhibiting herbicide typically used in conservation and no-tillage production systems for nonselective burndown control of emerged weeds or as a directed spray with specialized application equipment in crop. Paraquat controls a broad spectrum of weeds, and the lack of soil residual allows rotational crop flexibility similar to glyphosate and glufosinate. Paraquat rapidly desiccates leaf tissue and thus does not translocate well enough to control perennial weeds. Paraquat is relatively inexpensive, but its high mammalian toxicity imposes significant use and handling restrictions.

UTILITIES AND LIMITATIONS OF CURRENT AND FUTURE HERBICIDE-RESISTANT CROP TECHNOLOGIES

Current HR Crop Technologies. A large number of transgenic and nontransgenic HR crops have been commercialized (**Table 4**).

Table 4. Summary of Commercial Herbicide-Resistant Crops in North America (Adapted from Reference *44*)

herbicide type		crop	year available
bromoxynil		cotton	1995
		canola	2000
ACCase inhibitor	- sethoxydim	corn	1996
	- quizalofop-P	sorghum	2011
glufosinate		canola	1995
		corn	1997
		cotton	2004
glyphosate		soybean	1996
		canola	1996
		cotton	1997
		corn	1998
		alfalfa	2005
		sugar beets	2005
imidazolinones		corn	1993
		canola	1997
		wheat	2002
		rice	2002
		sunflower	2003
specific sulfonylureas		soybean	1994
		sunflower	2006
		sorghum	2011
triazines		canola	1984

These HR crops generally eliminated all crop injury concerns and allowed the grower to select new herbicide options with improved weed activity and environmental safety. Before the advent of GR crops, most thought that the utility of HR crops would be limited to complementing selective herbicides (*45*−*47*). The full impact of HR crops really started in 1996 with the sales of GR soybeans. Since then, the speed at which growers adopted GR crops has been unprecedented in corn, soybeans, and cotton (*4*). Success came despite an unpopular "grower contract" and strong objections by biotechnology opponents to potential unknown effects on the environment and human health and the ethical question of interfering with the natural order.

Nontransgenic HR Crops. With the exception of Canada, nontransgenic HR traits are essentially unregulated. Scientists have used a wide range of nontransgenic techniques to create crops with resistance to a number of herbicide MOAs (**Table 5**). For example, the first commercial ACCase-resistant crop was a sethoxydim-resistant (SR) corn with an altered ACCase created using tissue culture selection (*49*). A second ACCase trait is in the final stages of commercialization for use in sorghum. This trait was transferred with traditional breeding methods from feral sorghum (shattercane, *Sorghum bicolor* L. Moench) that had evolved ACCase herbicide resistance because of agronomic practices (*50*).

Creating HR crops for ALS-inhibiting herbicides has been quite successful using tissue culture selection, pollen mutagenesis, microspore selection, seed mutagenesis, and gene transfer from close weedy relatives that had evolved herbicide resistance because of agronomic practices (*50*−*52*). Today, at least seven different ALS-resistant crops are commercially available (*53*). In all cases, resistance is due to an ALS mutation with three general crop phenotypes: broad resistance to ALS herbicides; resistance only to imidazolinone and pyrimidinylthiobenzoate herbicides; and resistance only to sulfonylurea and triazolopyrimidine herbicides (*54*, *55*).

Table 5. Summary of Nontransgenic Herbicide-Resistant Crops (Adapted from Reference *48*)

selection method	herbicide type	crop
whole plant	triazine	canola
seed mutagenesis	terbutryne	wheat
	sulfonylurea	soybean
	imidazolinone	wheat
		rice
tissue culture	sulfonylurea	canola
	atrazine	soybean
	imidazolinone	corn
	sethoxydim	corn
cell selection	imidazolinone	sugar beet
pollen mutagenesis	imidazolinone	corn
microspore selection	imidazolinone	canola
transfer from weedy relative	ALS inhibitor	sunflower
		sorghum
	ACCase inhibitor	sorghum

Table 6. Summary of Currently Available Transgenic Herbicide-Resistant Corn, Soybeans, and Cotton

crop	resistance trait	trait gene	trait designation	first sales
cotton	glyphosate	*cp4 epsps*	MON1445	1996
		two *cp4 epsps*	MON88913	2006
		zm-2mepsps	GHB614	2009
	glufosinate	*bar*	LLCotton25	2005
corn	glyphosate	three modified *zm-2mepsps*	GA21	1998
		two *cp4 epsps*	NK603	2001
	glufosinate	*pat*	T14, T25	1996
soybean	glyphosate	*cp4 epsps*	GTS 40-3-2	1996
		cp4 epsps	MON89788	2009
	glufosinate	*pat*	A2704-12	2009

Glyphosate-Resistant Crops. Nontransgenic HR crops were only modestly successful; the big success with HR crops began with transgenic GR soybeans in 1996 (**Table 6**). Growers perceived glyphosate resistance as the ideal herbicide trait because glyphosate controls over 300 annual and perennial weeds, has flexible application timings, and does not have any rotational crop restrictions (*56*). GR crops allowed growers to use glyphosate as an in-crop selective herbicide and replace more expensive, selective herbicides that controlled a narrower weed spectrum and had other issues (e.g., crop tolerance).

Within a decade after glyphosate became commercially available, the search began to find crop resistance to glyphosate. Nontransgenic approaches were not successful, and transgenic approaches were difficult and not initially successful (*57*). Initial attempts to find any natural enzymes in crops that could metabolically inactivate or were insensitive at the target site failed. Eventually, a gene for a glyphosate insensitive EPSPS with enzymatic characteristics similar to plant EPSPS was isolated from a common soil bacterium, *Agrobacterium tumefaciens* strain CP4, which was surviving in a glyphosate manufacturing waste stream in Luling, LA (*57*). This *cp4 epsps* gene has been used to develop GR soybeans, cotton, corn, canola, alfalfa (*Medicago sativa* L.), bentgrass (*Agrostis stolonifera* L.), and sugar beet (*Beta vulgaris* L.) (*5*).

Glyphosate resistance became the most rapidly adopted technology in the history of agriculture (*5*), but the first GR crops were not perfect. The timing, rate, and number of glyphosate

Table 7. Publicly Disclosed Non-glyphosate Transgenic Herbicide-Resistant Traits with Significant Utility in Corn, Soybeans, and Cotton (Adapted from Reference *48*)

herbicide/herbicide class	characteristics	reference
2,4-D	microbial degradation enzyme	*60*
ALS inhibitors	resistant ALS from many sources	*61*
ACCase inhibitors and synthetic auxins	microbial, aryloxyalkanoate dioxygenase	*62*
dicamba	*Pseudomonas maltophilia*, *O*-demethylase	*63*
HPPD inhibitors	overexpression, alternate pathway, and pathway flux	*38*
PPO inhibitors	resistant microbial and *Arabidopsis thaliana* PPO	*41*
multiple herbicide classes	glutathione *S*-transferase, *Escherichia coli*	*64*
	P450, *Zea mays*	*65*

applications had to be restricted to ensure crop resistance (*5*), and there were reports of a "yield drag" (*58*). A new generation of herbicide traits currently in development will be combined with current and new glyphosate traits to help continue to improve this technology and extend the transgenic weed management revolution.

Glufosinate-Resistant Crops. Glufosinate-resistant crops have been commercially available as long as GR crops (**Table 6**), but have not been as successful for a number of reasons, particularly because of the higher cost of glufosinate and its more restrictive application timings. Glufosinate resistance is widely available, not only because of its utility as a herbicide trait but also because it has been often used as a marker for other traits, particularly insect resistance traits. Resistance to glufosinate is due to metabolic inactivation of the parent molecule by either of two homologous enzymes, phosphinothricin *N*-acetyltransferase (PAT) or basta *N*-acetyltransferase (BAR), that catalyze the acetylation of glufosinate (*59*). Both genes were isolated from soil microorganisms, *pat* from *Streptomyces viridochromogenes* and *bar* from *Streptomyces hygroscopicus*. Cotton and soybean growers who are troubled by difficult to control GR weeds such as Palmer amaranth and waterhemp may rapidly adopt glufosinate-resistant crops and the use of glufosinate. "Dual stack" crop cultivars that include resistance to both glufosinate and glyphosate are now commercially available in cotton, soybeans, and corn and provide growers a choice between two broad-spectrum herbicides as well as an array of naturally selective herbicides to diversify their weed management practices.

Future HR Crop Technologies. Whereas GR crops have been very successful, the evolution of GR weeds was faster and more widespread than many expected. This rapid evolution of GR weeds and the lack of any new selective herbicides with novel MOAs is encouraging HR crop technology to evolve again. The next wave of technologies will combine resistance to glyphosate and other herbicides to provide growers with more herbicide options with different MOAs as well as the possibility of using herbicides with both foliar and soil residual activity. Scientists have discovered a plethora of herbicide traits that can be combined with glyphosate resistance to make multiple HR crops (**Table 7**). If used correctly, multiple HR crops with these traits can sustain the usefulness of glyphosate.

Resistance to Synthetic Auxin Herbicides. Corn is relatively tolerant to most synthetic auxin herbicides, but soybeans and cotton are sensitive, and scientists have long sought a transgene to give these crops resistance and allow the use of auxin herbicides (*66*). Auxin herbicides control a broad spectrum of broadleaf weeds, including most known GR broadleaf weeds. Because auxin herbicides act rapidly at multiple receptors and compete with an essential plant hormone pathway, making crops resistant by modifying the site of auxin action is difficult. In addition, these receptors respond differently to different auxin herbicide classes, for example, phenoxyacetates (e.g., 2,4-D), pyridinyloxyacetates (e.g., fluoroxypyr), benzoates (e.g., dicamba), picolinates (e.g., picloram), and quinolinecarboxylates (e.g., quinclorac) (*67*). So far, metabolic inactivation has proven to be a more successful strategy.

A gene encoding for dicamba monooxygenase (DMO), an enzyme that deactivates dicamba, was cloned from a soil bacterium, *Stenotrophomonas maltophilla*, and used to make dicamba-resistant soybeans (*63*, *68*). The DMO enzyme encodes a Rieske nonheme monooxygenase that metabolizes dicamba to 3,6-dichlorosalicylic acid (DCSA). The complete bacterial dicamba *O*-demethylase complex consists of the monooxygenase, a reductase, and a ferredoxin. Electrons are shuttled from reduced nicotinamide adenine dinucleotide (NADH) through the reductase to the ferredoxin and finally to the terminal component DMO. Researchers can successfully express DMO in the cell nucleus with or without a transit peptide as well as in the chloroplasts where the monooxygenase would have a source of electrons produced by photosynthesis and where transgenic proteins can often be expressed at higher levels. Commercialization of dicamba-resistant soybean and cotton is anticipated mid-decade.

A family of *aad* genes that code for aryloxyalkanoate dioxygenase provides resistance to certain auxin herbicide (*69*, *70*). The *aad-12* gene was isolated from *Delftia acidovorans* and codes for a 2-ketoglutarate-dependent dioxygenase that inactivates phenoxyacetate auxins (e.g., 2,4-D) and pyridinyloxyacetate auxins (e.g., triclopyr and fluoroxypyr) (*62*). This trait, DHT2, is being developed in soybeans. A second gene known as *aad-1* was isolated from *Sphingomonas herbicideovarans* and inactivates auxins and ACCase-inhibiting herbicides in the class known as FOPs (e.g., fluazifop) (*62*). This trait, DHT1, is being developed in corn. Both traits are reported to provide resistance to high rates of 2,4-D with no adverse agronomic effects.

The 2,4-D and dicamba resistance traits will always be used in stacks with at least one other herbicide-resistance trait (*62*, *71*). The expected increased use of auxin herbicides will increase the potential for off-target movement and injury to sensitive broadleaf plants. Due to this potential environmental problem, the herbicide and trait providers will likely introduce improved herbicide formulations with better use directions before the traits are commercialized mid-decade (*33*, *72*). Ironically, this risk of off-target movement could drive more rapid adoption of auxin traits because growers will want to protect their soybean and cotton crops from nearby applications of auxin herbicides.

Resistance to HPPD Inhibitors. In some ways, HPPD-inhibiting herbicides are ideal to complement glyphosate. Many HPPD herbicides have soil residual activity and control key broadleaf weeds that have already evolved resistance to glyphosate. Increased resistance mechanisms for HPPD herbicides include a less sensitive target site, overexpression of the enzyme, alternate pathway, increasing flux in the pathway, and metabolic inactivation (*38*, *48*). Crops resistant to HPPD herbicides have been in field development tests since 1999, but there have been no technical disclosures of HPPD resistance traits under developments thus far. Bayer CropScience in collaboration with Mertec LLC (Adel, IA) and M.S. Technologies LLC (West Point, IA) and Syngenta (Basel, Switzerland) have independently announced plans to develop HPPD-resistant crops. Bayer CropScience recently disclosed that they were developing soybeans resistant to three herbicide types: glyphosate, glufosinate, and HPPD herbicides (e.g., isoxaflutole) (*17*). Isoxaflutole can provide preemergence (PRE) and postemergence (POST) control of a relatively

broad spectrum of annual weeds with soil residual activity. The "triple stack" offers the advantage of enabling the use of two herbicide MOAs to which weeds have not yet evolved resistance.

Resistance to Other Herbicide Types. Resistance to other herbicide types could also have significant utility. For example, transgenic crops resistant to PPO-inhibiting herbicides have been developed, and the technology even received the trade name Acuron (*41*). The first PPO-resistant corn used a double-mutant PPO, PPO-1, from *A. thaliana*. Similarly, PPO-resistant rice used overexpression of the naturally resistant *Bacillus subtilis* PPO gene to confer resistance. Other approaches including increasing gene copy number and tissue culture to select for overexpression of wild type PPO genes have also been successful (*41*). The broad-spectrum weed control and soil residual activity of PPO herbicides could be useful in corn, soybeans, and cotton, but the existing widespread resistance to this class among some *Amaranthus* species limits the value of the technology.

A transgenic DHT1 trait also gives resistance to ACCase-inhibiting herbicides by degrading the alkanoate side chains to a hydroxyl of the FOP class of ACCase herbicides (e.g., quizalofop) (*62*). DHT1 corn reportedly tolerates postemergence applications of quizalofop of up to 184 g/ha with no adverse agronomic effects. This trait has utility in corn where commercial ACCase herbicides are not naturally selective. In addition, the specificity of its inactivation could allow the use of other ACCase herbicide types for HR volunteer corn management in rotational crops.

Most herbicide traits only give resistance to herbicides with one MOA. Metabolic inactivation systems based on cytochrome P450 monooxygenases (P450) and glutathione transferase (GST) have the potential to inactivate a wide range of herbicide types (**Table 7**). For example, native P450 enzymes can metabolically inactivate acetanilides, bentazon, dicamba, some ALS-inhibiting herbicides, isoxazoles, and urea herbicides (*65, 73*). The chemical specificity of this metabolic system may offer the unique potential to allow growers to use herbicides in the same MOA to control weeds in one season and still manage any feral volunteers with a herbicide in the same MOA in the next year.

Multiple HR Crops. No single herbicide resistance trait will be sustainable if the grower uses only the single herbicide type that the trait enables recurrently. The weed problems and their technological resolution must evolve together. Multiple HR crops will help by allowing the use of new herbicide mixtures with multiple modes of action, but agriculture must manage this technology objectively and pragmatically, balancing short-term and long-term interests, so as not to create a "transgenic treadmill" (*18*).

The lack of soil residual activity has encouraged multiple in-crop applications glyphosate, as many as four or more applications per growing season. Some of the new, multiple HR crop technologies will enable herbicide applications with soil residual activity and thus help growers to reduce selection pressure on the weed community by glyphosate (*74*). For example, the glyphosate and ALS trait stack that has recently been deregulated in the United States can allow the use of ALS-inhibiting herbicides with soil residual that are too phytotoxic to use on conventional crop cultivars (*75*). This stack consists of a metabolic system to inactivate glyphosate based on an enhanced glyphosate acetyltransferase enzyme from the soil bacterium *Bacillus licheniformis* (Weigmann) Chester (*76*) and a highly resistant ALS allele (HRA) with two mutations, tryp574leu and pro197ala (*75*).

A wide array of other combinations of current and new herbicide resistance traits is expected within the next decade. If used correctly, these multiple HR crops will provide new uses for existing herbicides to help growers better manage weeds and help sustain the utility of glyphosate and glyphosate resistance traits.

PATH FORWARD

Weed management dramatically changed with the widespread adoption of GR crops. Using glyphosate in GR crops made weed management too simple and convenient. Importantly, the high initial efficacy of glyphosate declined with repeated use, and current glyphosate-based weed management systems are in jeopardy as evidenced by the speed at which weed populations are evolving resistance. Still, glyphosate has not lost all utility; it controls more weeds more effectively than other herbicides, but it can no longer be applied alone anytime on any weed anywhere. Most growers still do not have any GR weeds in their fields and have time to implement proactive HR weed management practices to help sustain glyphosate. However, growers need to act now to diversify the herbicides and tactics they use, the crops they plant, their cultural practices, and field hygiene measures. The flexibility and range of alternative weed management practices will be narrow and require integration to replace glyphosate. These management practices will work better for the prevention rather than the control of GR weeds. Once present, GR weeds can be managed but are difficult if not impossible to eradicate.

Growers need new weed management options now. Current corn, soybean, and cotton cropping systems are based on a heavy reliance on glyphosate. Given the changes in weed populations that are being reported, it is of paramount importance that other weed management alternatives be identified and implemented quickly (*25, 77*). It is likely that no new herbicide or trait technology will match the impact of glyphosate and the first GR crops on agriculture. Growers will use these new technologies in combinations to fill in efficacy gaps and diversify weed management practices. Initially, it may look like an attempt to make glyphosate look "as good as it used to be". Some traits such as glufosinate resistance will enable a broad-spectrum alternative to glyphosate. Others will enable options with soil residual activity or new MOAs to control key GR weeds. Some HR crop technologies may benefit from incremental improvements in efficacy and properties of herbicides within long-standing herbicide MOAs that companies are still commercializing (*37, 42*).

Growers must diversify their weed management practices now (*78*). The more growers diversify, the less the risk that weeds will evolve herbicide resistance. Diversification may make weed management more complex, but growers must not use new HR crop systems in the same way that some used initial GR crops, as a means to rely only on one herbicide until it is no longer effective and then switch herbicides. If growers use the new HR crops and the herbicides that they enable properly, HR crops will expand the utility of currently available herbicides and provide long-term solutions to manage GR weeds.

HR crops will not replace the need for technical innovations, particularly the discovery of herbicides with new MOAs. Diversification will be much easier if growers can chose from among multiple effective and economical weed management options. In areas of the world that have not yet adopted GR crops, growers can learn from the experiences in North and South America. Growers must not wait, but implement best management practices as soon as new trait and herbicide technologies are available. By using diverse weed management practices, growers will preserve the utility of herbicide resistance traits and herbicide technologies and help maintain profitable and environmentally sustainable crop production systems for future generations.

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Modelling the Effectiveness of Herbicide Rotations and Mixtures as Strategies to Delay or Preclude Resistance[1]

JONATHAN GRESSEL and LEE A. SEGEL[2]

Abstract. Herbicide-resistant populations have evolved only in monoculture and/or monoherbicide conditions at predictable rates for each compound and weed. No populations of triazine-resistant weeds have appeared in corn where rotations of crops and herbicides or herbicide mixtures were used. This is due to the greatly reduced competitive fitness of the resistant individuals, which could be expressed only during rotational cycles, and also to the greater sensitivity of resistant individuals to other herbicides, pests, and control practices ("negative cross-resistance"). The model presented here describes how an understanding of all of these factors can provide strategies to decrease the frequency of the resistant individuals during rotation. Rotations or mixtures may not delay the rate of appearance of resistance to inhibitors of acetolactate synthase (ALS), where the fitness of resistant biotypes is claimed to be near normal. The best way to delay resistance to ALS inhibitors is to use those compounds with less persistence so that the selection pressure will be lowered. Too little is known about the frequency of resistance to other herbicides with target-site resistance–to dinitroanilines, to acetyl CoA carboxylase inhibitors, or to those situations where a single enzyme system confers resistance to a broad spectrum of seemingly unrelated herbicides. **Nomenclature:** Corn, *Zea mays* L.

Additional index words: Herbicide resistance, fitness, selection pressure, seedbank dynamics, triazine resistance, metabolic cross resistance.

INTRODUCTION

Weeds are evolving resistance to different herbicides at different rates. Resistance can be avoided by understanding and analyzing the interacting factors involved in changing a sensitive weed population into a resistant one. These factors, described below, are inserted into models so that the quantitative importance of each factor can be evaluated. The model predictions favorably compare with the case histories of resistance. Newer models are described so that the effectiveness of different weed control strategies can be predicted better.

Weeds in North America have evolved resistant populations to herbicides only where there was monoculture with a single family of herbicides. The only exceptions until recently have been where different herbicides having the same site of action were used (e.g., a rotation of photosystem-II inhibiting herbicides) (17). Resistant-weed populations have evolved in wheat (*Triticum aestivum* L.) monoculture in England and Australia, where high selection pressure herbicides with different sites of action but the same putative mode of degradation are rotated (17, 19, 37, 41). Such metabolic cross resistances likely will evolve elsewhere.

The appearance of resistance in monoculture and/or mono-herbicide usage was described by a simple population model (22, 23) that integrated the following: a) the selection-pressure of the herbicide (based on the rate used, its effectivity with particular weeds, and its persistence); b) the germination dynamics of the weeds (over the season and from the soil seedbank); c) the initial frequency of resistant individuals deriving from natural mutations in the susceptible population; d) the fitness of the evolved resistant biotypes in competition with the wild type under field conditions; and e) the number of generations (seasons) the herbicide was used. This model helps to understand why resistance evolved in monoculture to the high selection pressure *s*-triazines in corn but not to herbicides exerting lower selection pressure, such as the thiocarbamates, chloroacetamides, and phenoxy herbicides, in similar weeds growing in this crop (22, 23).

It is consistent with the model that populations of weeds did not evolve that resist 2,4-D [(2,4-dichlorophenoxy)acetic acid] and MCPA [(4-chloro-2-methylphenoxy)acetic acid] in wheat. The model predicts the inevitably rapid appearance of weed biotypes resistant to the high residual activity sulfonylureas, as well as to chlorotoluron [*N*′-(3-chloro-4-methylphenyl)-*N*′*N*-di-

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methylurea], diclofop-methyl {methyl ester of (±)-2-[4-(2,4-dichlorophenoxy)phenoxyl]propanoic acid}, and mecoprop [(±)-2-(4-chloro-2-methylphenoxy)propanoic acid)] in weeds of wheat.

Resistant biotypes evolved first in those weeds where the herbicides exert the highest selection pressure. For example, diclofop exerts a higher selection pressure on ryegrass (*Lolium* spp.) species than on wild oat (*Avena* spp.) species. In agronomic terms, this herbicide is more effective on ryegrasses, and ryegrasses indeed have evolved resistance with greater rapidity (41).

Because of a lack of field ecology data, our early model inaccurately predicted evolution of resistance where herbicide mixtures and rotations were used. Vast areas of corn have received herbicide rotations including *s*-triazines for 30 yr, and resistant populations have not appeared. Our early model did not adequately consider the then unknown effects of the extreme lack of fitness in many resistant biotypes in the seasons that triazines were not used. The previous model (22, 23) correctly predicted that mixtures could delay considerably the evolution of resistance, but the lack of field data on selection pressure of mixtures left it to the reader to insert the correct parameters into the equations and the accompanying figures.

A new model (24) considers what happens during the "off" years when a given herbicide is not used and predicts that some high selection pressure herbicides can be used sparingly in rotation, possibly even after resistance has appeared. The data show the urgent need for further research concerning the physiological ecology of resistant weed populations.

MODELS

The original monoculture model described different possible rates of enrichment of resistant individuals in populations, until the populations were predominantly resistant (22, 23). Different constant proportions of susceptible and resistant plants germinated and survived to the end of the season, and susceptible and resistant individuals had (different) constant seed yields. Resistant individuals initially formed an exceedingly small fraction of the population, certainly a well-warranted assumption during the years of resistance enrichment, until there were sufficient numbers of individuals for resistance to be evident.

Various factors involved in evolution were found (after certain simplifications) to satisfy a simple algebraic equation giving our early model (22, 23). Solving this equation gives the frequency of resistant individuals after n years of treatment.

$$N_n^{(R)} = N_o^{(R)} \left[1 + \frac{f\alpha}{n}\right]^n \quad [1]$$

The factors included in the original monoculture monoherbicide model equation are the following:

$N_o^{(R)}$ is the very low frequency of resistant individuals in the population before it is exposed to the herbicide. Resistance is sustained in the population in the absence of herbicide by a balance between new mutations to resistance and depletion of a proportion of resistant individuals by their lesser fitness in the absence of selection. This results in a resistance fraction somewhat lower than the mutation frequency. Mutants conferring more fitness than the wild type become the wild type. Mutant fitness can be near neutrality, and the mutants would be found in different proportions at various geographical areas due to genetic "drift." $N_n^{(R)}$ is the proportion of resistance in the population after n seasons of treatments.

f, the competitive reproductive fitness, measures the compounded relative robustness of resistants in competition with susceptibles during germination, establishment, growth, pollination, seed production, and survival. By definition, fitness always is measured with resistant and susceptible plants in competition with each other in the absence of herbicide. When they are grown separately, the resistant individuals are often less "productive," but the competitive fitness differential is usually greater (Table 1)[3].

α, the selection pressure, is the ratio of the fraction of resistants that abound in the population after a herbicide application during that season to the corresponding fraction of susceptibles. Thus, early or late-germinating susceptible individuals that produce seeds are considered in this "effective-kill", in contrast with the initial weed control usually measured by weed scientists. For example, if the herbicide kills 90% of the susceptibles and none of the resistants, then $\alpha = 10$; if 99% of the susceptibles are controlled and none of the resistants, then $\alpha = 100$. The susceptible individuals would in-

[3]Letters following the symbol # are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

Table 1. Lower productivity and competitive fitness of *s*-triazine-resistant biotypes[a].

Species[b]	Productivity	Competitive fitness (1:1)[c]	Reference
	(Resistant ÷ Susceptible)		
Smooth pigweed	0.90	0.18	1
Common groundsel	0.47	0.43	28
Common lambsquarters	0.75	0.08	52
Lateflowering goosefoot	1.00	1.78	52
Rapeseed	0.76	0.28	21

[a]Productivity is measured by growing resistant and susceptible biotypes separately; competitive fitness is measured by growing them in a mixture. In both cases, seed yield was measured, where "seed" may include fruit or whole flower depending on study cited.

[b]Smooth pigweed (*Amaranthus hybridus* L. # AMACH); common groundsel (*Senecio vulgaris* L. # SENVU); common lambsquarters (*Chenopodium album* # CHEAL); lateflowering goosefoot [*Chenopodium strictum* Roth. var. *glaucophyllum* (Aellen) H. A. Wahl. # CHESG]; rapeseed (*Brassica napus* L.)

[c]Fitness of 1:1 mixture.

clude those missed by sprays (in refuges) and "immigrants" due to seed and pollen influx.

The gene flow due to seeds and pollen usually is minimal, in the range of meters per years when actually measured (2, 30, 43). Immigration of resistant seed can be a problem when there is strong selection pressure in a field. One "pioneer" seed can form a large colony. Immigrating susceptible seed will have little numerical impact because of the larger reservoir of susceptible seed already in the field during the first cycles of selection for resistance.

$\bar{n}$ is the average number of years that a seed remains viable in the seed bank.

The predicted rates of enrichment of resistance are plotted from Equation [1] with different scenarios of selection pressure, seedbank dynamics, fitness, and initial frequency in Figure 1. These various measures of resistance change by a constant factor each year, giving rise to an exponential increase in resistant individuals (Figure 1). Estimated parameter values (that should have come from experimentation) were inserted into the equation to generate the scenarios. They were based on a limited data base, mostly from corollary systems, such as heavy metal tolerance. Research groups have begun to accurately measure weed-herbicide interactions for more precise estimates.

The frequency of resistance in the population starts at a low value and increases by a constant factor each year. In spite of the exponential increase, detecting resistant individuals in a field will be hard until resistance is at a level of 10 to 30% of the population.

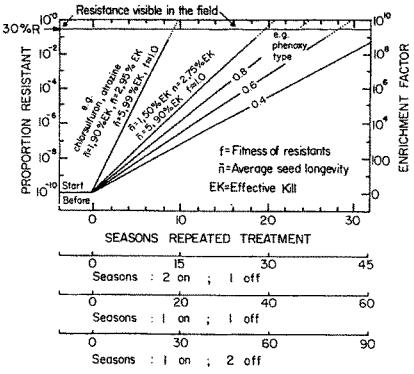


Figure 1. Presumed effects of herbicide rotations using the original model. Overall average effect of scenarios with different selection pressures [$\alpha = 10 =$ 90% effective kill (EK); $\alpha = 100 = 99\%$ EK; $\alpha = 2.0 = 50\%$ EK], seed bank dynamics ($\bar{n}$), the average seed duration in the soil, and *f* differential fitness. The different scales give the different rotational scenarios from monoherbicide to one treatment in three seasons. Calculated from equations in (22, 23). Modified from (24).

Messages from the model. *a) The importance of selection pressure.* Selection pressure is the most influential agronomic variable, with the largest effect on the evolution of resistance (Figure 1). For example, the atrazine [6 -chloro -*N*' -(1 -methylethyl) -1,3,5 -triazine-2,4 -diamine] and chlorsulfuron {2-chloro-*N*-[[(4-methoxy-6-methyl -1,3,5 -triazin -2 -yl)amino]carbonyl]benzenesulfonamide} levels required to kill different weeds vary over more than an order of magnitude. The selection pressure of both herbicides is greatest on annual broadleaf species requiring the lowest rates for weed control. The selection pressure is least for those weeds requiring the highest herbicide levels, i.e., usually the grasses. At a given herbicide rate, both herbicides control broadleaf species better, i.e., selection pressure is lower on grasses.

The first weeds to evolve atrazine-resistant populations were common groundsel, pigweed species, and lambsquarters species. The last to evolve resistance were the grasses, as the model predicted. Various broadleaf weeds already have evolved chlorsulfuron resistance in the field, at the level of the target enzyme. This occurred under repeated selection pressure of this

recently introduced and highly persistent herbicide. It was also easy to select for resistance to this herbicide in the laboratory (7, 26). If these two preferentially broadleaf controlling herbicides were used in conjunction with selective grass-controlling herbicides, their use rates could be decreased and the selection pressure on broadleaf weeds lowered.

Single annual use of herbicides with the greatest persistence always will exert the highest selection pressure (Figure 1). The triazines, dinitroanilines, and sulfonylureas meet this criterion of persistence with season-long control, and resistance has evolved to all these groups (16). 2,4-D and other phenoxy herbicides and thiocarbamates have short biological persistence in the soil, and resistance has not evolved to them. Resistance need not have evolved so rapidly. There are less persistent triazines than atrazine (such as cyanazine) {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropane-nitrile] and far less persistent sulfonylureas for wheat than chlorsulfuron and metsulfuron {2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)-amino]carbonyl]amino]sulfonyl]benzoic acid} (5). If these less persistent analogs had been used, the selection pressure should have been lowered and the evolution of resistant populations delayed.

Paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) resistance has evolved and may seem to contradict the theory's emphasis on persistence, as paraquat immediately loses biological activity upon reacting with soil colloids. The lack of residual persistence was balanced by farmer persistence. Paraquat resistance occurred where this herbicide was used 5 to 10 times during each season in monoherbicide usage.

b) Seedbank dynamics. The longer the life in the seedbank, the greater the buffering effect of susceptible seed from previous years, decreasing the rate of evolution of resistance. Common groundsel has evolved triazine resistance in orchards, nurseries, and roadsides where there was no mechanical cultivation but not in cultivated corn fields. The groundsel seed is incorporated into the soil seedbank in such corn fields, where it is viable for many years (54). All groundsel seed falling on undisturbed soil on roadsides or orchards either germinates or dies during the following season (42). Resistance thus evolved where there was the lowest average seed bank life time $\bar{n}$ as predicted. Such information must be considered in formulating strategies for resistance management. Many other species do not have a seedbank under specific agronomic situations, i.e., in minimum-till agriculture where $\bar{n} = 1$.

c) f, fitness of resistant individuals. The lack of fitness of resistant individuals can have a strong dampening effect on the evolution of resistance but only when it can be expressed, i.e., when the herbicide is not present. Thus, in monoherbicide culture, the lack of fitness can have little influence with persistent herbicides but could be effective with the less persistent herbicides. This is another reason to avoid persistent compounds, especially in monoculture.

Resistance to herbicides with the same site of action. The original model predicted that rotation or mixing of herbicides with the same site of action (and thus similar mode of resistance) will have the same effect as using a single herbicide. This was expected on biochemical grounds as well; plants resistant to atrazine had target-site cross resistance to all triazines, some phenylureas, uracils, etc., all at the same site in Photosystem II. The use of corn/soybean [*Glycine max* (L.)Merr.] or atrazine/metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5-(4*H*)-one] or sulfonylurea/imidazolinone rotations with various crops thus should be contraindicated if the various herbicides are effective on the same spectrum of weeds (17, 18, 23). For the same reason, the genetic engineering of atrazine-resistant soybean for use in monoherbicide culture would be misdirected unless the atrazine usage in corn were to be replaced by other herbicides.

Cross resistances to herbicides due to degradation. Metabolic cross resistances to insecticides and drugs having vastly different modes of action are common and are documented to the level of molecular biology (16). Such cross resistances to herbicides with different modes of action are a recent occurrence (17, 18, 27, 37, 41). Rigid ryegrass (*Lolium rigidum* L.), frequently called annual ryegrass, that evolved resistance to diclofop had cross resistance to chlorsulfuron as well as to all other wheat-selective herbicides (27). Blackgrass (*Alopecurus myosuroides* Huds. # ALOMY) that evolved resistance to chlorotoluron was cross resistant to chlorsulfuron, pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], and diclofop (37).

Similar metabolic cross resistances to insecticides and drugs often were traced to the evolution of higher levels of nonspecific esterases, hydrolases, or monooxygenases. The resistances in blackgrass and rigid ryegrass can be abolished by adding specific monooxygenase inhibitors along with the herbicide (19, 20, 32, 41). Genetically engineering new modes of herbicide

resistance into wheat also could alleviate the problem (18, 19). Such data, along with the knowledge that wheat seems to have selective resistance to herbicides by mono-oxidations, suggest that these weeds may have evolved a biochemical mimicry, i.e., they have evolved a system similar to wheat to degrade wheat-selective herbicides (17, 18, 19).

MODELLING ROTATION

The model as shown in Figure 1 does not adequately account for events in the "off years" during rotations if the competitive fitness of the resistant biotype is low. Resistance is shown (Figure 1) to evolve at a fixed rate as a function of the number of generations or seasons a weed was treated with a particular herbicide. This means that if it would take 6 yr for resistance to occur in monoculture corn with atrazine as the sole herbicide, it either would take 9 yr in a corn/corn/wheat (or soybean) rotation where atrazine is used for control 2 of every 3 yr; or 12 yr in a corn/wheat (or soybean) rotation where atrazine is used every other year, or 18 yr in a corn/wheat/soybean rotation where atrazine is used once in 3 yr.

When the model was formulated a decade ago, triazine resistance appeared in areas of the cornbelt where such rotations were used, as there had been 6 to 10 yr of atrazine usage since it was introduced. Yet, resistant populations only appeared in monoculture, monoherbicide corn.

Mixtures. Few farmers in the center of the cornbelt grow monoculture corn, unlike areas to the east of the cornbelt where triazine resistance appeared in corn. Cornbelt farmers use rotations and/or mixtures of triazines with chloroacetamide herbicides, which allow the use of less atrazine and thus lower the selection pressure. The chloroacetamides also kill pigweeds (*Amaranthus* spp.) and lambsquarters (*Chenopodium* spp.) as well as grass weeds. Mixtures substantially delay resistance, both according to the model (22) and from field data, although the magnitude of this effect is yet unclear.

The reason for the efficacy of mixtures to delay resistance can be manyfold. The frequency of resistance is lowered to the compounded frequency for each component. If the frequency of resistance to one component is 10^{-7} and the other 10^{-8}, the compounded frequency is 10^{-15}. The lower rates of each component used decreases the selection pressure for each, adding to the delay in resistance. The fitness to each component is also compounded, which should give low fitness for the individual resistant to both compounds in a mixture. Simulations of this are illustrated in (22, 23). Certain mixtures are not "mixtures" in the sense of delaying resistance: those that act at the same site (e.g., two photosystem II inhibitors) and those that are degraded by the same enzyme system (e.g., possibly all the herbicides used in wheat that are degraded by monooxygenases).

The models for mixtures are described in greater detail, with figures showing scenarios, in (23). Herbicide rotation may be the only strategy remaining to delay the evolution of triazine resistance in corn as the chloroacetamide herbicides used in mixtures for corn are under attack for environmental reasons, and their use is restricted in many areas and forbidden in others.

We have incorporated better data into an updated model, to show how rotation has been a better strategy than previously predicted. The newer data and model emphasize the highly reduced fitnesses of the resistant biotypes, which are of greater magnitude and importance than had initially been expected.

Lack of fitness of resistant weeds – a major consideration. The initial model used an average fitness differential for all generations treated (Figure 1). The fitness differential between resistant and susceptible individuals essentially never can become apparent with herbicides such as triazines that give season-long control, as there is no time when the herbicide is not present for this differential to be expressed. Only the resistant biotypes can survive when the herbicide is present. Thus, the fitness differential is unimportant with triazines in monoherbicide culture but seems to be an important factor in delaying resistance to other herbicides with more ephemeral action.

The fitness differential is important when herbicide usage is stopped for a season or more. Resistant biotypes are often more susceptible to some of the herbicides and cultivation procedures used in the rotational years (negative cross resistance). We have modified the model to consider what happens to resistant individuals in the "off" years when the herbicide in question is not used (24).

The resistant individuals, initially present at very low frequencies in the field, must compete with the crop and with resistant members of other weed species. When the herbicide is not present, they must compete with susceptible members of the same and other species

that germinate throughout the year. During the evolution of resistant populations, only intraspecific competition has been considered, except for one study (53). More data are needed from the agro-ecologists on the important of interspecific competition, including that with crops and weeds.

The first studies on competitive fitness were performed by pregerminating seedlings of resistant and susceptible individuals, interplanting them at fixed distances, and allowing them to grow to maturity (9). The yields of the resistant and susceptible biotypes were measured. In almost all cases where this was done, the susceptible individuals outyielded the resistant ones (Table 1).

Most competition experiments have not been made with material that has nuclear isogenicity where resistant and susceptible alleles are in otherwise identical nuclear backgrounds. Nuclear isogenicity is easy to achieve by using reciprocal hybrids when dealing with cytoplasmically inherited triazine resistance. An otherwise identical plastome in such crosses cannot be guaranteed. This eventually may change when plastomes are engineered by site-directed mutagenesis. Repeatedly backcrossed material also provides near-nuclear isogenicity with a large differential in competitive fitness (21) (Table 1). There seems to be no fitness difference between resistant and susceptible individuals of lateflowering goosefoot (53). Lateflowering goosefoot is a slow-growing species, and photosynthetic electron transport probably does not limit its growth.

A few triazine-resistant grasses have been reported to be more productive and competitively fit than the wild type (56), but this must be checked under more rigorous conditions. In general, one must be wary of reports of evolved fitnesses that are better than the wild type. Considering the long periods that species have evolved, the wild type in any given location should have evolved to optimal fitness. Spurious reports of high fitness may result form various interrelated functions: a) fitness was not measured from germination on; b) density dependent functions were not considered; c) reactions to environmental conditions may have differed; d) germination characters and seed bank dormancies may have differed; and e) fitness was not measured under field conditions.

Some mutations to resistance may engender larger losses of fitness than others. Triazine resistance may lead to an extreme case of fitness loss that could be due to many other linked mutations in the chloroplast genome. Triazine resistance may evolve in populations containing a plastome-mutator gene (3). This could explain some of the unfitness of triazine-resistant plants as well as the variabilities of plastid fitness. Any plant with triazine-resistant plastids should have other mutations in its plastids. Deleterious nuclear mutations can be bred or selected out of populations because of chromosomal segregation along with somatic and meiotic recombination (crossing over). This is not as easy with chloroplasts, where recombinations are negligible. Thus, the unfitness in atrazine-resistant plants may not be due to the *psb*A gene mutation, as has been argued on biophysical grounds (31, 34, 47, 49).

Target site mutations or gene amplifications in enzymes present in low quantities may not exert such strong effects on resistance as was found with triazine resistance. Fitness measurements must be performed carefully with resistant weeds as soon as resistant populations appear.

The measurement of fitness. As we consider fitness a major factor in delaying resistance, the measurement of fitness is described in detail below.

a) Measurement from germination. Weeds produce hundreds to thousands of seeds to replace one plant. Most perish before maturity, many during overwintering, early germination, and establishment. The competition before establishment is probably the fiercest. Competitive fitness studies should be measured at this stage, but this usually has not been done. The simplest way to do this is to plant mixtures of resistant and susceptible seed and to ascertain which plants are resistant and susceptible by a nondestructive test or by using leaf pieces. The seeding should be done at various depths and densities and preferably under field conditions to best mimic the natural environment. As seeds from resistant plants are often smaller than those from sensitive plants, there surely should be a definite competitive disadvantage to resistance when the selecting herbicide is not present.

b) Density dependence of fitness. Density dependence of fitness has not been measured adequately. For example, it is not clear why annual bluegrass (*Poa annua* L. # POAAN) biotypes resistant to triazines evolved only in genotypes that were prostrate and not in those that are erect (10). The lack of competition in triazine-treated fields possibly allowed the prostrate types to spread. There are variations in the density dependence of diclofop-resistant rigid ryegrass (27). The resistant plants were more fit than the sensitive ones under

sparse than under dense spacing. The fitness also varies at different ratios of resistant to susceptible individuals in competition. Only the data from a 1:1 mixture are given in Table 1. The original data show that the resistant biotypes are even less fit than the 1:1 mixture when they are in a lower proportion in the populations. The data suggest that fitness should be measured at various densities and ratios of sensitive to resistant individuals, especially those that more closely approximate the initial low frequencies of resistant individuals in the field.

c) Environment and fitness. A lowered optimal temperature for growth and photosynthesis for resistant biotypes is one of the common (12) but not universal (51) pleiotropic effects found with triazine resistance. Interpretation of these findings can be complicated. The earlier germination and "head start" can be highly advantageous under many greenhouse conditions; but in the field, it can be devastating. A late frost will decimate the earlier germinating resistant population and leave the later germinating susceptible population. This demonstrates why fitness must be measured under field conditions to indicate what happens in the field.

d) Changing seedbank dynamics. Repeated and strong selection for resistant weeds under monoculture easily can abolish the "spaced out" germination typical of weeds during the season and over many seasons. This higher immediate germination of resistant individuals versus the susceptible in many fitness tests (e.g., 36) may give real but misleading results that do not approximate fitness properties under field conditions.

e) Narrow genetic base. Isozyme electrophoresis studies of resistant populations always have shown that resistant biotypes at least initially possess a much narrower genetic base than adjacent susceptible populations (10, 11, 14, 53). This is due to the "founder effect" of mutants in diverse populations measured soon after evolution. In genetic evolutionary terms, this suggests that under certain narrow conditions the resistant populations may be more fit than the wild type; but under broad and varying environmental conditions they will be less fit.

In many cases, this might mean that the fitness will increase slowly due to "nuclear compensation" from repeated crossing with the wild type susceptible population. The fundamental biochemical lesion caused by triazine resistance probably will prevent fitness from improving in that case. One can increase the yield of triazine-resistant species by intercrossing. Still the reciprocal intercrosses with the sensitive biotype as female parent always outyielded the resistant offspring in such crosses (4). The effect of interbreeding on increasing fitness will have to be checked with other types of herbicide resistance.

The importance of negative cross resistance. Resistant pests often are controlled more effectively than the wild type by a variety of agents. This phenomenon, known as "negative cross resistance," has been reported with antibiotic-resistant bacteria in medicine and in fungicide-resistant pathogens and insecticide-resistant arthropods (16).

Similar data can be found for weeds (Table 2), which indicates that the phenomenon should be explored as a part of resistance management procedures. Triazine-resistant individuals were often less fit under the agronomic procedures used during the "off" years when triazines were not used and procedures with negative cross resistance were used. We have no accurate counts of the decay of resistance in populations when triazine usage was stopped due to high resistance levels.

Negative cross resistance has been found with many weed control and biological factors:

a) Standard mechanical cultivations of mixed resistant and sensitive common groundsel populations reduced the resistant individuals more than the susceptible ones (54).

b) The differential lack of fitness often can be due to other biotic factors. It was found that triazine-resistant rutabagas (*Brassica napobrassica* L.), which nominally produced yields as high as the near iso-nuclear susceptible biotype, were totally and selectively decimated by a viral infection[4]. Triazine-resistant smooth pigweed was selectively eaten by beetle larvae, and triazine-resistant common lambsquarters was more susceptible to fungal disease than the wild types[5].

c) Many herbicides are more toxic to resistant individuals than to susceptible ones (Table 2). Table 2 only contains data for negative cross resistances, but these are not the preponderant cases and are not universal. Still, they can be elucidated and incorporated into strategies for managing resistant weeds, both before and after populations become preponderantly resistant.

The negative cross resistances in atrazine-resistant weeds include herbicides that act at or near the same

[4]Souza-Machado, V. 1987. Personal communication. Univ. Guelph, Guelph, Ont., Canada.

[5]Ritter, R. 1988. Personal communication. Univ. MD., College Park, MD.

Table 2. Negative cross resistance of herbicide-resistant biotypes.

Primary resistance Species[a]	Negative cross resistance[b]	Parameter measured[c]	I_{50}[d] R/S	Ref.
Triazines				
Redroot pigweed	Dinoseb	FW	0.27	13
	Fluometuron	Thylakoids	0.22	39
	DNOC	Thylakoids	0.5	39
Common lambsquarters	Dinoseb	FW	0.27	13
Rapeseed	Dinoseb	FW	0.66	13
Common groundsel	Dinoseb	FW	0.21	13
Horseweed	DNOC	Thylakoids	0.1	33
Kochia	2,4-D	FW	d	44
American willowherb	Oxyfluorfen	FW	d	8
	Paraquat	FW	d	8
	Pyridate	FW	d	8
	Chlorpropham	FW	0.46	6
Dinitroanilines				
Goosegrass	Chlorpropham		d	50
Mecoprop				
Common chickweed	Benazolin	FW	0.53	35
MSMA–DSMA				
Common cocklebur	Paraquat	FW	0.50	25
	Bentazon	FW	0.65	25
Chlorsulfuron				
Jimsonweed	Imazaquin	FW	0.03	45
Paraquat				
Horseweed	Glufosinate	PS	0.26	40

[a]Species not defined previously: horseweed [*Conyza canadensis* (L.)Cronq. # ERICA]; kochia [*Kochia scoparia* (L.)Schrad. # KCHSC]; american willowherb (*Epilobium ciliatum* Rafin. = *E. adenocaulon* Hausskn # EPIAC); goosegrass [*Eleusine indica* (L.)Gaertn. # ELEIN]; common chickweed [*Stellaria media* (L.)Vill. # STEME]; common cocklebur (*Xanthium strumarium* L. # XANST); jimsonweed (*Datura innoxia* Mill. # DATIN).

[b]Chemicals not defined previously: dinoseb [2-(1-methylpropyl)-4,6-dinitrophenol]; fluometuron [*N,N*-dimethyl-*N'*-[3-(trifluoromethyl)phenyl]urea]; DNOC (4,6-dinitro-*o*-cresol); oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene]; pyridate [*O*-(6-chloro-3-phenyl-4-pyridazinyl)-*S*-octyl carbonothioate]; chlorpropham (1-methylethyl-3-chlorophenylcarbamate); benazolin (4-chloro-2-oxo-3(2*H*)-benzothiazole-acetic acid); bentazon [3-(1-methylethyl)-(1*H*)-(2,1,3-benzothiadiazin-4-(3*H*-one 2,2-dioxide]; imazaquin [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid]; glufosinate [ammonium (3-amino-3-carboxypropyl)methylphosphinate]; MSMA (monosodium salt of methylarsonic acid); DMSA (disodium salt of methylarsonic acid).

[c]FW = fresh weight; PS = photosynthetic CO_2 fixation; thylakoids = photosystem II activity of isolated thylakoids.

[d]The I_{50} is the concentration lowering the parameter measured by 50%; R = resistant; S = susceptible. Where no I_{50} R/S ratio is given, there was a large degree of negative cross resistance at a single herbicidal rate.

site in photosystem II (DNOC and dinoseb) as well as herbicides acting on other photosystems (paraquat) or at totally different sites. There was negative cross resistance to other tubulin-binding herbicides in dinitroaniline-resistant goosegrass (Table 2) but not to six commercial herbicides on this weed (38). The negative cross resistance to imazaquin (Table 2) occurred in only one of 21 chlorsulfuron-resistant mutants. The other mutants had varying levels of co-resistance to imazaquin.

Resistant biotypes sometimes grow better in the presence of the herbicide than without the herbicide. For instance, Lipecki[6] found that a triazine-resistant biotype of smooth pigweed grown with 5 kg ha^{-1} simazine (6-chloro-*N,N'*-diethyl-1,3,5-triazine-2,4-diamine) had double the dry weight per plant than without the herbicide. This lower resistant-biotype productivity when the herbicide is not present results in a stronger lack of competitive fitness in the "off" years.

MODIFIED MODEL FOR ROTATIONS

The long-term effect of rotational strategies is easier to calculate by deriving new equations that better consider the rotational perturbations. We have modified Equation [1] to give a new basic equation

$$H_{p,q} = [1 + \delta\ (\alpha f_{on} - 1)^p\ [1 - \delta(1 - f_{off})]^q \quad [2]$$

where:

H is the overall enrichment factor giving the increase in resistance following a period of p "on" seasons of herbicide application and q "off" seasons without herbicide;

δ, the fraction of seeds leaving the seedbank each year, replaces $\bar{n}$, the average residence time as the factor describing seed bank characters.

The derivation of Equation [2] and the simplifications, approximations, and assumptions involved are detailed elsewhere (24). Equation [2] can be rearranged to solve for various parameters to predict the effects of different agricultural scenarios. The p "on" years and the q "off" years can occur in any order during the $p + q$ year period that is under study.

There is little added effect of a small "off" fitness (e.g., $f_{off} < 0.3$), as there is a significant loss of resistant seeds during the off years due to the decimation of these seeds in the seedbank by natural causes (rotting, insects, etc.). This loss will not be replaced by the small addition that emanates from less fit resistant seeds. Note that the "off" factor is simply f_{off} in the absence of a seedbank ($\delta = 1$), as the only factor affecting seed number will be seed deposition, however small. If $\delta = 1$, then a strong influence of f_{off} can be expected.

[6]Lipecki, J. 1988. Personal communication. Adademii Rolniczej W. Lublinie, St.-Leszczynskiego 7, Lublin, Poland.

Various applications of this newer model are plotted in Figures 2 to 5, showing examples of how this model can be used to predict what might happen in real field situations, when different herbicide treatments are used in various rotations.

The effects of various rotations on the rate of evolution of resistance are plotted using Equation [2] to show the effects of fitness during the season when the herbicide was used and a different (constant) fitness for seasons when not used (Figure 2). There is hardly any real added delay due to rotation on resistance when the resistant individuals have near-normal fitness (Figures 2 D to F). Actually, Figure 1 and Figures 2 D to F do not differ agronomically if the lines in Figure 2 are smoothed. This high fitness may be the situation with the weeds having resistance at the level of acetolactate synthase (based on productivity, not competition experiments). Thus, in such cases, with high fitness, the model states that rotation is of little assistance in truly delaying resistance. The only delay will be for the number of generations the particular herbicide is not used. In such cases, only lowering the selection pressure will delay resistance. Obviously, the model must be validated by agro-ecological experimentation.

When there is a large fitness differential between resistant and susceptible individuals (as with triazine-resistant weeds), there will be a delaying effect due to fitness (Figures 2 A to C), and the effect is greatest when selection pressure is lowest. The plots describe the reduction of the proportion of resistant individuals in the off years. There are even some situations at low selection pressure where resistant individuals disappear in "off" years more rapidly than they are enriched for in "on" years. Thus, rotation can be advantageous. When there is negative cross resistance, the fitness differential is even greater, and the results can be considered by using the effects of a lower fitness value f for this period.

Scenarios with a slow rate of overall enrichment, showing that it will take many years for resistant populations to become a major problem, are summarized in Table 3. The (log) factor of enrichments at the end of 9- and 15-yr periods are given. When this factor is compared with the initial frequency of resistance (N_o), it can be estimated whether resistant populations should have evolved. If N_o is 10^{-20} (a guess for the N_o of triazine resistance), fitness is 0.3 or less, and selection pressure is low, i.e., the effective kill is less than 95%, then we see that resistant populations will not evolve

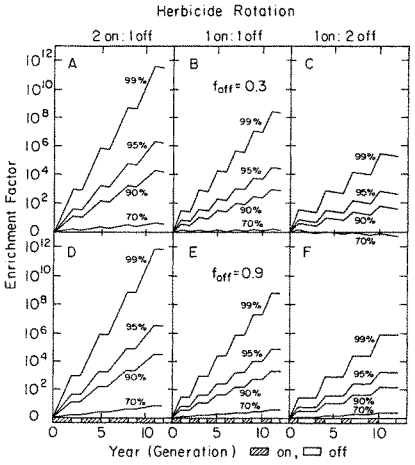


Figure 2. The effect of herbicide rotation on the rate of resistance enrichment. Three rotational scenarios are shown for herbicides with different selection pressures expressed as effective kill. "On" refers to the year the herbicide in question is used and "off" the year it is not used. The two fitnesses are those thought to represent triazine resistance (Table 1) (A to C; f = 0.3) and those thought to represent sulfonylurea/ALS resistance (7) (D to F; f = 0.9). The f_{on} = 1. The weed seeds in the seedbank are presumed to have a 2-yr residence time. Calculated from equations in (24).

under any of these scenarios. Triazine resistance would only appear in 15 yr in monoherbicide culture where the effective kill is 99% (Log H = 22.3, which makes up for the resistance frequency of 10^{-20}).

With chlorsulfuron, N_o should be 10^{-6} to 10^{-8} (7, 26, 45, 48) versus the estimates of 10^{-20} for triazine resistance. This high initial frequency explains why chlorsulfuron resistance evolved so rapidly. It is not clear that one need actually consider whether mutations to resistance are dominant or recessive; there may be only a small frequency difference between the two types in diploid organisms (55). This is because recombination (crossing over) can increase homozygous recessive frequencies in populations considerably. The selection pressure of 2,4-D is so low that no resistant populations occurred in 35 yr of monoculture wheat (29) as would be expected from Table 3.

The important predictive uses of this model are twofold:

Table 3. (Log) Enrichment of resistant individuals in weed populations over 9- and 15-yr periods under different herbicide rotations[a].

Rotation strategy	Effective kill[b]	9-yr period			15-yr period		
		Fitness in "off" years			Fitness in "off" years		
		0.9	0.5	0.3	0.9	0.5	0.3
	(%)	[Log 10 of enrichment factor (Log H)]					
No rotation	50	1.0	1.0	1.0	1.7	1.7	1.7
	90	5.1	5.1	5.1	8.5	8.5	8.5
	95	7.4	7.4	7.4	12.4	12.4	12.4
	99	13.4	13.4	13.4	22.3	22.3	22.3
2 on; 1 off	50	0.6	0.5	0.4	1.1	0.8	0.6
	90	3.4	3.2	3.1	5.6	5.3	5.2
	95	4.9	4.7	4.6	8.2	7.9	7.8
	99	8.9	8.7	8.6	14.3	14.5	14.4
1 on; 1 off	50	0.5	0.3	0.2	0.8	0.4	0.2
	90	2.8	2.6	2.4	4.4	4.0	3.8
	95	4.1	3.8	3.7	6.5	6.1	5.9
	99	7.4	7.1	7.0	11.8	11.4	11.2
1 on; 2 off	50	0.3	-0.1	-0.3	0.4	-0.1	-0.4
	90	1.6	1.3	1.1	2.7	2.1	1.8
	95	2.4	2.0	1.9	4.0	3.4	3.1
	99	4.4	4.0	3.8	7.3	6.7	6.4

[a]The table is best used to compare expected mutation frequencies for resistance and to see whether resistance would be expected with different management regimes. Examples of such frequencies would be *ca* 10^{-6} for a dominant monogenic trait, *ca* 10^{-12} for recessive monogenic mutants if unproven theory is accepted, or *ca* 10^{-7} if experimental data from another biological system (55) is accepted. A minus sign indicates a negative enrichment for resistance. It is presumed that the fitness of triazine-resistant weeds 0.3 to 0.5 and the fitness of ALS level sulfonylurea resistance is *ca.* 0.9. Calculated from equations in (24).

[b]The effective kill (the percent control over the whole season) of 50, 90, 95, and 99% are equivalent to $\alpha = 2, 10, 20, 100$, respectively in Equations [1] and [2]. A seed bank release of $\delta = 0.3$ (half-life in seedbank of 2 yr) and f_{on} of 1.0 were assumed.

a) to design rotational and mixture scenarios to delay resistance as much as possible yet still to obtain cost-effective weed control using herbicides such as chlorsulfuron and atrazine, which are among the least expensive and most active selective herbicides for wheat and corn, respectively;

b) once resistance has occurred, to design strategies whereby herbicide usage is stopped for a number of years, until the level of resistance is below a certain proportion, and then resume limited use, during a certain proportion of the rotation cycle. Such strategies have been designed for insecticides where there already are predominantly resistant populations. These populations become diluted because of fitness and the migration of susceptible individuals into the area (16). The treatment strategies are designed so the maximum proportion of resistant individuals does not exceed a certain limit percentage.

With this newer model, a kill percentage can be calculated that will give any (within reason) desired degree of resistance enrichment after p "on" years and q "off" years. This was done to calculate various types of enrichment for both minimum tillage and other situations where the seed bank can be negligible. It also can be used for tillage and other seed bank situations under conditions where various acceptable levels of enrichment were allowed or to stasis where no net increase in the frequency of resistance occurs. To achieve such stasis would be nirvana. There are theoretical situations, perhaps even field situations, where stasis might be achieved. Different treatment regimes with low selection pressures giving stasis without a seedbank are shown in Figure 3. Given this information, weed control of strategies can be designed where resistant individuals will not be enriched. One cannot obtain stasis with continuous use of a herbicide under conditions giving adequate weed control. One still can ensure that the rate of enrichment is low.

The model is plotted so selection pressures that provide resistance stasis as a function of the duration of seed remaining in the seedbank are shown in Figure 4 for various fitnesses. Three possible rotation strategies are examined. Some cases can have no enrichment at all for resistance. If the effective kill by 2,4-D in wheat is only 50 to 60% due to late weed germination, then under low fitness and a 1:1 rotation there is no enrichment. Stasis can even be obtained with selection pressures above 90% if there is a 2- or more yr interval between the treatments with the herbicide. Stasis is impossible with high selection pressure herbicides in

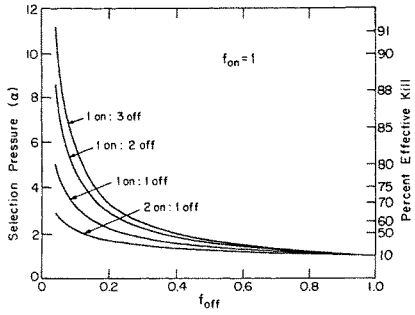


Figure 3. Resistance stasis for situations where there is no seedbank buffering as actually occurs in minimum-till agriculture. Values of selection pressure (α) and fitness (f) in "off" years that will allow no enrichment for resistance (stasis), when f_{on} = 1 (24). The effective kills are based upon total lack of herbicidal effect on the resistant individuals. Calculated from equations in (24).

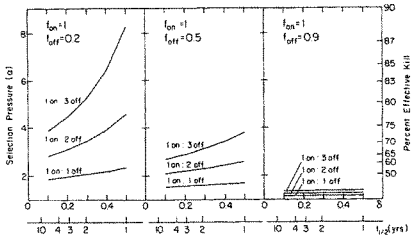


Figure 4. Conditions leading to a resistance stasis under various selection pressures (α), and with different rotation strategies or with different weed seed dynamics in the seedbank. The selection pressure also is shown as "effective kill" (the percent reduction in sensitive propagules over a whole season) with the assumption that the rare resistant individuals are totally unaffected by the herbicide. Here f_{on} = 1 while f_{off} takes a relatively low value in (A) and a higher value in (B) and (C). The f_{off} of 0.2 and 0.5 in A and B approximate those found with triazine resistance, and the f_{off} of 0.9 in (C) approximates the target site resistant mutants to acetolactate synthase inhibitors. The seedbank dynamics are given as δ, the fraction remaining in the soil at the end of a season, and $t_{0.5}$, the half-life of seeds in the seedbank. Calculated from equations in (24).

usual rotational sequences. Long duration of resistant seed in the seedbank is a deterrent to stasis, as resistant seeds act as a buffer for longer periods.

While stasis may be hard to achieve, a doubling of the frequency of resistant individuals every 3 yr would be acceptable. Selection pressures are depicted in Figure 5 that will just double the frequency of resistant individuals in the population in 3 yr with the "1-on: 2-off" strategy. At an intermediate duration of seed residence in the seed bank, the doubling of resistance occurs at the lowest selection pressures. This means that if the frequency of resistance is 10^{-6}, then it will take almost 60 yr for resistant populations to predominate.

CONCLUDING REMARKS

The model depicted from Equation [2] in Table 3 and Figures 2 to 5 describes the enrichment for resistant individuals in the population but only when they are still a minuscule proportion of the total population and not when a population actually nears resistance. As the resistant population becomes large, some of the simplifications that are valid only at lower resistant frequencies cannot be used. The complex equations from which Equation [2] was derived (24) must be used. These cast light on the new considerations that are needed for resistance management once there is a preponderance of resistant individuals. The consideration of the lower fitness in the "off" years can be refined further when actual data are available on fitness in different field situations with different species as well as more information on the dimunition of resistant populations under various agronomic and herbicide treatments.

Information on fitness also will be needed for many types of herbicide resistance to allow more accurate design of management strategies. What is clear is that all resistances so far have occurred in monoherbicide/monoculture or in equivalent situations that have the same effect. Weed species either receiving the same number of treatments, as in monoculture but over a longer period in rotational situations, or receiving mixtures that control the species have not evolved resistant populations.

Many resistant individuals are less fit (Table 1) because of the nature of the target site mutation conferring resistance or due to the high levels of gene products required to detoxify the herbicide. In other cases, resistant individuals may not be too unfit; or because of their nuclear inherited nature, many of the deleterious co-mutations may be lost. Chlorsulfuron-resistant mutants may not have lower productivity (7), but the competitive fitness of these plants has not been mea-

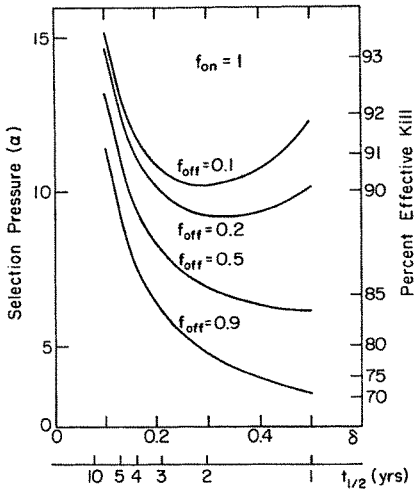


Figure 5. Selection pressures that cause a doubling of the proportion of resistant individuals in the population every 3 yr. The data are given for a 1 on: 2 off rotational strategy, with different fitness in the off years (f_{on} = 1) and different seed bank dynamics. The seedbank dynamics are given as δ, the fraction remaining in the soil at the end of a season, and $t_{.5}$, the half-life of seeds in the seedbank. Calculated from equations in (24).

sured. There are theoretical reasons, based on the site of the mutation on the gene, to assume that these sulfonylurea-mutants need not be very unfit (46). Thus, rotating chlorsulfuron with other herbicides may not delay resistance beyond the number of "off" years, as it has with atrazine and trifluralin [2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine]. The added value of rotation will be only where the fitness is low in the off season.

Both the models and the limited field data suggest that the best tactics to prevent or to delay the appearance of resistant populations are:

a) to use herbicide treatments with the minimum selection pressure giving cost-effective weed control. Such treatments will not give near total weed control but leave behind enough susceptible seeds each year to dilute out resistant seeds;

b) to use herbicide mixtures of compounds acting at different sites of action and having different modes of degradation, preferably with herbicides having strong negative cross resistances;

c) to use rotations of herbicides having different sites of action and different modes of degradation, preferably where the weeds have negative cross resistance to the herbicides; and

d) to employ mechanical cultivations in the rotations, especially if they preferentially control unfit resistant biotypes.

These criteria are hard to meet with some monocultures, especially wheat. Wheat probably has only a single mode of degradation (19). In such situations, it is necessary either a) to rotate crops to allow herbicide rotation; b) to rotate with herbicides having a placement selectivity (e.g. 15) that is not related to herbicide metabolism in wheat; (c) to find synergists that preferentially inhibit herbicide degrading enzymes in the weeds of wheat (20).

Those high-selection-pressure herbicides having resistant mutants that are fit will be problems. The only alternative is to replace these with less persistent herbicides of the same group having less selection pressure and thus partially offsetting the lack of fitness.

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Review/Analysis

Are Herbicide Mixtures Useful For Delaying the Rapid Evolution of Resistance? A Case Study[1]

ROGER P. WRUBEL and JONATHAN GRESSEL[2]

Abstract. Mixtures of herbicides have been proposed as strategies to prevent or delay the evolution of resistance to the resistance-prone sulfonylurea and imidazolinone herbicides that inhibit acetolactate synthase. These herbicides have become or are becoming widely used in soybean, wheat, rice, and other major crops. For a mixture to be efficacious in preventing resistance, the less resistance-prone component(s) should have the following traits compared to the vulnerable herbicide: a) control the same spectra of weeds; b) have the same persistence; c) have a different target site; d) be degraded in a different manner; and e) preferably exert negative cross-resistance. We compared the proposed mixing partners for use with several widely used acetolactate synthase inhibiting herbicides to these criteria and found that: a) all have somewhat different weed spectra; e.g. none control common cocklebur as well as imazaquin or imazethapyr in soybean, or kochia as well as chlorsulfuron in winter wheat; b) all are far less persistent than these vulnerable herbicides. Less persistent sulfonylureas are now on the market but are in limited use. Late in the season, the mixing partner is not present while the vulnerable herbicide remains active; c) most have different target sites; d) in soybean most mixing partners are degraded differently than vulnerable herbicides. In wheat virtually all herbicides used without safeners are degraded by monooxygenases, thus it is impossible to meet this criterion in this crop; e) none of the mixing partners exert negative cross-resistance. The present mixtures may have superior or more cost-effective weed control properties than the acetolactate synthase inhibitors used alone, but they do not meet all the criteria for resistance management. Not meeting the key criteria of identical control spectra and equal persistence aggravates future resistance problems, as has happened with insecticides. **Nomenclature:** Chlorsulfuron, 2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; cocklebur, *Xanthium strumarium* L. #[3] XANST; kochia, *Kochia scoparia* (L.) Schrad. # KCHSC; corn, *Zea mays* L.; rice, *Oryza sativa* L.; soybean, *Glycine max* (L.) Merr.; winter wheat, *Triticum aestivum* L.

Additional index words: Imidazolinone resistance, sulfonylurea resistance; ALS-inhibitor resistance.

INTRODUCTION

The extensive and continuous use of herbicides over the last four decades has resulted in the evolution of weeds resistant to normally phytotoxic chemicals. Since the first reports of triazine-resistant weeds in the mid-1960s (19, 36), well over 100 weed species have been identified that have evolved biotypes with resistance to at least one and occasionally more than one herbicide type (46, 47, 53, 54, 55). Reports of evolution of newly resistant biotypes continue to increase steadily (46, 47), although many cases probably go unreported. Several disturbing trends have been recognized. Herbicide resistance seems to be appearing after fewer years of exposure to newer herbicides than to the older inhibitors of photosystem II; many weeds have shown a capacity to evolve resistance; and some of the resistant biotypes may have similar reproductive fitness to that of susceptible biotypes (1, 2, 45, 53, 55, 58). These trends indicate that resistance problems are accelerating and that management of weeds could become more difficult in the future due to herbicide resistance.

Several strategies have been proposed to prevent or

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

delay the evolution of resistant weed populations. Among them are rotation of crops, rotation of herbicides with different modes of action, use of combinations of herbicides with different modes of action, and conservation of susceptible weeds (37, 38, 39, 47, 59, 69, 70). These strategies aim to reduce the selection pressure favoring weed biotypes that have evolved herbicide negating mechanisms.

Groups of structurally dissimilar herbicides inhibiting acetolactate synthase (ALS)[4], including sulfonylureas, imidazolinones, and triazolopyrimidines, are especially prone to losing efficacy due to the rapid evolution of resistant weeds (55). While some weeds have evolved resistance to single chemical groups, other populations of the same species have evolved target site cross-resistance to ALS inhibitors of other chemical groups, even though they were subjected to only one (29, 41, 65, 72, 73, 75, 83).

Herbicide manufacturers acknowledge that there is serious potential for ALS-inhibitor resistance problems in weeds (4, 6, 13, 61) and have founded the ALS/AHAS[4] Inhibitor Resistance Working Group within their Herbicide Resistance Action Committee. Member companies of the working group have devised strategies that they believe will prevent or severely delay evolution of resistance in weeds. The core of the strategies is to use mixtures of herbicides with different modes of action to combat resistance. Their approaches also involve recommendations to growers to use weed surveys and weed thresholds to determine the actual need for herbicide use before spraying, to combine cultivation with herbicide treatment, and to rotate crops (13). The producers of the ALS inhibiting herbicides are promoting these strategies based on the continued use of their herbicides in combination with herbicides having different modes of action (4, 6, 61).[5,6,7] The continued use of imidazolinone herbicides in combination with other herbicides is even recommended to treat fields where imidazolinone-resistant weeds have been identified.[5] Still, the ALS/AHAS Resistance Working Group formed by industry has provided only general recommendations and no binding specific recommendations, due in part to the different economic interests of its member companies.

The primary objective of this paper is to examine the herbicide mixtures being recommended to determine if they can be potentially effective resistance management tools. We first discuss the characteristics of the herbicides of interest and then the theoretical considerations related to using herbicide mixtures for managing herbicide resistance. We then describe the characteristics required of a competent mixing partner. Finally, we analyze the likelihood of present recommendations for use of herbicide mixtures with imidazolinones in corn/soybean and with sulfonylureas in wheat cropping systems to meet the criteria delineated for effective herbicide resistance management.

CHARACTERISTICS OF ALS-INHIBITING HERBICIDES

The ALS inhibitors are relatively new classes of herbicides. The imidazolinones were developed and first marketed by the American Cyanamid Company in 1986. The sulfonylureas originally developed by E. I. Du Pont de Nemours and Company were first introduced in 1982 and are now manufactured by several companies. The triazolopyrimidines were developed by Dow-Elanco Corporation and are just now appearing on the market. These three chemistries of herbicides all inhibit acetolactate synthase, the first enzyme in the synthesis pathway leading to branched-chain amino acids (31, 52, 66, 71, 79, 80). In sensitive plants, the synthesis of valine, leucine, and isoleucine is curtailed. Most naturally resistant crops rapidly metabolize these herbicides and render them ineffective (73). The ALS inhibitors have a number of favorable characteristics from weed control and environmental perspectives. Most of these herbicides are highly efficacious for control of a broad spectrum of dicot weeds, and to a lesser extent monocots, as well as many perennials (Table 1). They are applied at relatively low rates, have very low mammalian toxicity, and are not mutagenic in the Ames test (86). Unfortunately, the ALS inhibitors are among the herbicides considered to be at highest risk for the evolution of resistance in weeds because they have a single target site, are effective against a wide spectrum of weeds, and many are relatively persistent, often providing season-long control of germinating weed seeds (55). Also, the various sites of mutations for resistance are not near the active site of the enzyme and thus there is no fitness loss due to a lower affinity for the normal substrates (77).

The incidence of herbicide resistance to ALS inhibitors,

[4]Abbreviations: ALS, acetolactate synthase (AHAS, acetohydroxyacid synthase is an often used synonym).

[5]Shaner, D. 1993. Personal communication, American Cyanamid Company, Princeton, NJ 08543.

[6]Dahmer, M. 1993. Personal communication, American Cyanamid Co., Princeton, NJ 08543.

[7]Sekely, K. 1993. Personal communication, American Cyanamid Co., Wayne, NJ 07470.

Table 1. Efficacy of imidazolinone herbicides (imazaquin or imazethapyr)[a] for dicot and monocot weed control in soybeans.

Dicot weeds (efficacy ≥ 75%)
Cocklebur
Jimsonweed (*Datura stramonium* L. # DATST)
Common lambsquarters
Pigweeds
Black nightshade (*Solanum nigrum* L. # SOLNI)
Common ragweed (*Ambrosia artemisiifolia* L. # AMBEL)
Smartweeds
Wild sunflower (*Helianthus annuus* L. # HELAN)
Velvetleaf
Burcucumber (*Sicyos angulatus* L. # SIYAN)
Monocot weeds (efficacy ≥ 55%)
Crabgrass (*Digitaria sanguinalis* (L.) Scop. # DIGSA)
Fall panicum (*Panicum dichotomiflorum* Michx. # PANDI)
Giant foxtail (*Setaria faberi* Herrm. # SETFA)
Shattercane (*Sorghum bicolor* (L.) Moench # SORVU)
(Volunteer) corn
Barnyardgrass (*Echinochloa crus-galli* (L.) Beauv. # ECHCG)
Yellow foxtail (*Setaria glauca* (L.) Beauv. # SETLU)
Woolly cupgrass (*Eriochloa villosa* (Thunb.) Kunth # ERBVI)
Yellow nutsedge (*Cyperus esculentus* L. # CYPES)

[a]Data adapted from (11).

particularly sulfonylureas, is increasing. Since the first discovery of prickly lettuce (*Lactuca serriola* L. # LACSE) resistant to the sulfonylurea herbicide chlorsulfuron, in 1987 (57), 13 other weed species with ALS-resistant populations have been confirmed with expanding geographic areas being affected (73). Cross-resistance of weed biotypes to other ALS-inhibitors augments the potential problem. Patterns of cross-resistance of weeds to ALS-inhibitor herbicides within and among the chemical families are highly variable and unpredictable. Weed biotypes resistant to one ALS-inhibitor herbicide exhibit varying levels of cross-resistance to other ALS inhibitors (24, 29, 30, 41, 57, 65, 72, 75, 76, 78, 81).

CRITERIA FOR EFFECTIVE MIXTURES FOR RESISTANCE MANAGEMENT

Herbicide mixtures have been discussed and modeled as a means of preventing or delaying the evolution of resistance in weeds (33, 38, 39, 59). There is also extensive theoretical and experimental literature on the use of insecticide and fungicide mixtures (26, 28, 49, 50, 56, 70, 74, 82). We know of no field studies specifically designed to examine the effectiveness of herbicide mixtures compared to other methods of weed resistance management, but there are "epidemiological" data. Extensive areas of monoculture corn have been treated continuously with triazine/chloroacetamide mixtures over 20 yr. Two broadleaf weed groups (*Chenopodium* spp. and *Amaranthus* spp.) that have often evolved triazine resistance when triazines were used alone, have never been reported to evolve resistance where these mixtures were used. The chloroacetamides have some limited activity on these two genera.

It has been posited that the use of herbicide mixtures combining different modes of action will substantially delay or preclude evolution of resistance to the more vulnerable or at-risk herbicides (4, 6, 61).[5,6,7] This is because weeds resistant to the vulnerable herbicide will be destroyed by the mixing partner, or at least be rendered relatively unfit compared to the wild type. For our discussion we will assume that two herbicides are used in mixture although more are possible. We refer to "mixtures" as only those combinations of herbicides where the partners both affect the same target weed (Table 2, sp. A). Often mixtures are used where each member affects different weed spectra, e.g., mixtures of grass and broadleaf herbicides (spp. B and C in Table 2). These latter mixtures, which increase weed control benefits, have no influence in delaying evolution of resistance in weeds they do not affect. They might even exacerbate resistance by controlling competing weeds, creating a more open niche for resistant biotypes. It is hard to assess, without experimentation, what the effect on the rate of evolution will be when the mixing partner has a moderate effect on a species excellently controlled by the vulnerable herbicide (Table 2, sp. D).

Evolution of target-site resistance to both the vulnerable and the partner herbicides is possible when mixtures are used, but should be much delayed compared to the appearance of resistant biotypes where each herbicide is used separately. The following reasoning, based on a compounded resistance frequency model, has been used to theoretically support this supposition: If the frequency of individuals resistant to each component of a pesticide in a mixture is independent in the susceptible species, then the joint probability of evolution of co-resistance to both herbicides in one individual equals the product of the

Table 2. Possible effects of mixtures on different species.

	Species			
Control by	A	B	C	D
	level of control[a]			
Vulnerable herbicide	++	++	0	++
Mixing partner	++	0	++	+

[a]0 = no control; + = partial control; ++ = control.

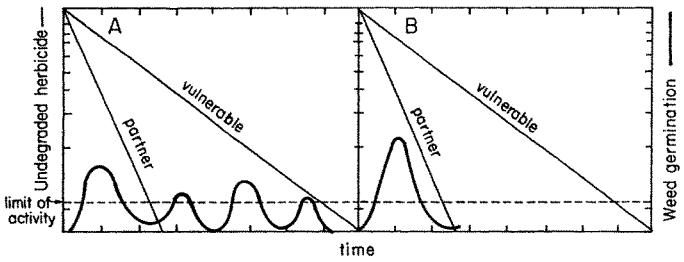


Figure 1. The persistence of herbicides in mixtures as related to germination flushes of weeds. The dissipation of herbicides is usually linear when herbicide remaining is plotted exponentially. The horizontal dashed line denotes when the herbicide is no longer biologically active. A. A situation where a weed species germinates throughout the growing season and many flushes are affected by only one component of a mixture. B. A situation where the weed species germinates in a single flush and is affected by both components of the mixtures.

probabilities of resistance for each partner [(28) for insecticides, (38) for herbicides]. For example: A weed has a natural mutation frequency of 10^{-5} for resistance to the vulnerable herbicide and 10^{-10} to a mixing partner having a different target site. The genes for resistance are inherited independently of each other (i.e., are not linked). Then, the joint probability of resistance to both pesticides in a mixture is $10^{-5} \times 10^{-10} = 10^{-15}$, which is very rare and is a smaller number. Thus, it would be expected that the simultaneous co-resistance to both herbicides, the only type that could appear, would evolve relatively slowly due to the minuscule initial frequency of doubly resistant individuals. Not only is the mutation frequency to joint resistance a compounded number, but any lack of fitness due to each mutation would also be compounded such that a weed with dual resistance may be far less fit and less competitive than wild type susceptible individuals (37, 38). However, the combination of herbicides can significantly increase the overall selection pressure on weeds by eliminating all susceptible genotypes due to use of full rates of both partners. In this case resistance to both herbicides may be delayed less than predicted by a compound model (38).

One major assumption of the compounded frequency of the resistance model described above is that the use of herbicides with different modes of action will not result in selection for weed biotypes possessing a single mechanism that detoxifies both partners. The evolution of generalized detoxification systems such as the monoxygenases common in wheat have been suggested to explain broad cross-resistance (33, 34) in blackgrass (*Alopecurus myosuroides* Huds. # ALOMY) (62) and rigid ryegrass (*Lolium rigidum* Gaudin # LOLRI) (64). There is some preliminary evidence (25, 27, 51) to support this idea of biochemical mimicry (33, 34) which is not universally accepted. (See the section below, "Evolution of metabolic resistance," for further discussion)

Characteristics of effective mixing partners for resistance management. It is possible that there will be cases of enhanced weed control by a mixture, but that such a mixture will be contraindicated vis-à-vis resistance management. Simply combining pesticides with different modes of action will not delay resistance if the efficacy and temporal activity of the mixed pesticides do not match (70). The mixing partner must effectively kill or severely weaken the weeds most sensitive to the vulnerable herbicide, because these weeds are the most likely to evolve resistance (38, 59). Both components should do so with nearly the same effectiveness; it may not be helpful if at the rate used, the mixing partner kills 75% of the weeds and the vulnerable kills 95%, unless the 20% remaining are severely inhibited such that they have a lesser reproductive capacity than the wild type. Otherwise, resistance could quickly evolve in the remaining 20% of weeds.

Both components of the mixture need to have similar persistence when weeds germinate throughout the cropping season. Otherwise, there will be a period when only the vulnerable one is present and effectively the target weed will not be exposed to a mixture at all (Figure 1A). Unlike crops, which have been selected to germinate uniformly and shortly after planting, seeds of many weed

species have many flushes of germination during a cropping season (20). If a susceptible weed has multiple flushes during the season, and the vulnerable herbicide has a longer period of activity than the mixing partner, then the vulnerable herbicide selects for individuals resistant only to it after the mixing partner has dissipated (Figure 1A). Thus, if the vulnerable herbicide has season-long activity (i.e., is selecting for resistant biotypes season-long, even when weed populations are below the economic threshold), it is critical that the mixing partner have the same persistence. This problem is accentuated when there is a long growing season and there can be more flushes of weeds producing viable seed in late season. Thus, a mixture may be more efficacious in northern, short season soybean areas than in southern areas with very long growing seasons.

A mixture that is not well matched for persistence can still be effective if the weeds germinate in a "single flush," without further germination, and both herbicides outlast the flush with equal efficacy (Figure 1B). Most cropping systems have many different weed species, so this circumstance can hold for some species but may often be irrelevant for the agroecosystem as a whole.

Methods could be devised for using a short-persistence mixing partner along with a long-persistence vulnerable herbicide. The short persistence mixing partner could be applied based on observations of weed germination or a farmer could repeatedly spray this herbicide throughout the season without such observations (not a recommended practice). The farmer might have to treat with the mixing partner late in the season (if registered) when application might confer no economic gain. It is also conceivable that a contact herbicide mixing partner, used late in the season, would not effectively eliminate all resistant weeds under the crop canopy. Unless there is very close overlap in the duration of efficacy between the two herbicides, a resistance management strategy based on their mixture is problematic and operationally complex.

The ideal mixing partner should have three other properties in addition to those just mentioned: Firstly, the mixing partner should have a different target site of action from the vulnerable herbicide. Thus, use of a triazine and a uracil or phenylurea can be contraindicated as mixtures, as they act on the same protein in photosystem II. The situation for ALS-inhibitors is slightly more complex because of the differential pattern of cross-resistance among weed species to ALS-inhibitor herbicides (30, 42, 73, 76). This pattern probably results in part from different or overlapping active sites for the herbicides on the ALS molecule (77). All weed biotypes resistant to one ALS-inhibitor are cross-resistant to at least some other ALS-inhibitors (73), and it is now impossible to predict the pattern of cross-resistance. Additionally, whereas one biotype of a species may have limited cross-resistance to other ALS-inhibitors, other biotypes of the same species may have broader overlapping spectra, i.e. the genes are present for broad spectrum ALS resistance. Thus, two ALS-inhibitors cannot be considered mixing partners for resistance management.

Secondly, the mixing partner should not be degraded in the same manner as the vulnerable herbicide. For example, if the vulnerable herbicide is degraded in the crop by a glutathione-transferase, the mixing partner should have no chemical site that can be attacked by that enzyme. This criterion could be a problem in wheat where all biochemically-selective herbicides seem to be degraded by monooxygenases in the crop (34). Herbicide mixtures for wheat would be subject to evolution of resistance in weeds capable of evolving increased levels of monooxygenase detoxification systems. This can come about by the evolution of higher levels of specific monooxygenases, by mutations coding for enhanced substrate (herbicide) specificity of one monooxygenase, or by mutations enhancing higher constitutive levels of all or many monoxygenases.

Thirdly, another useful attribute in a mixing partner would be to possess negative cross-resistance; i.e. where individuals resistant to the vulnerable herbicide are more susceptible than the wild type to the mixing partner. This would actually reduce the frequency of resistant alleles in the weed population. This strategy was first proposed for herbicides on the basis of laboratory data (40), and information on the existence of negative cross-resistance at the whole plant level has been published recently (18).

USE PATTERNS OF ALS-INHIBITING HERBICIDES, EVOLUTION OF RESISTANCE, AND HERBICIDE MIXTURES

Resistance in soybean. ALS-inhibiting herbicides were found to be highly efficacious in controlling weeds inadequately controlled throughout the season by other herbicides and thus came into rapid use (e.g., Table 3). Imidazolinone-resistant populations of common cocklebur were discovered in 1991 and 1992 in soybean fields in eight apparently independent locations along the Mississippi River valley.[5] In each case the fields were continuously planted to soybean and treated for several years with

imazaquin. At one site in Mississippi resistant biotypes were identified in 1991 after only three consecutive years of banded applications of imazaquin with cultivation between the rows (78).[8] This rapid evolution is especially worrisome, as it means that susceptible cocklebur could have grown in the areas between the rows. These susceptible biotypes should have diluted the number of resistant individuals in the seed bank and delayed the appearance of resistant populations. In Mississippi, cocklebur biotypes that evolved resistance due to exposure to imazaquin are cross-resistant to imazethapyr.[8] However, ALS extracted from these imazaquin-resistant cocklebur were sensitive to ALS-inhibitors of other chemical groups (78). An imazaquin-resistant biotype of cocklebur collected in Missouri was cross-resistant to other imidazolinones and sulfonyureas.[9] Because of the number of apparently unrelated resistant populations that have been detected so far, after just a few years of exposure, it is logical to conclude that cocklebur has the capacity to readily evolve resistance to the imidazolinones and possibly other ALS inhibitors.

Use of ALS-inhibitors in soybean and corn. The use of imidazolinone herbicides has been increasing dramatically in the U.S. The soybean area treated with either imazaquin or imazethapyr in Illinois, the largest soybean producing state, more than doubled from 20% in 1990 to 43% in 1992 (Table 3A). In Iowa, the soybean area treated with imidazolinones increased from 33% in 1990 to 52% in 1992. Across all major U.S. soybean producing states imidazolinone use increased from 27% of area treated in 1990, to 39% in 1991, to 47% in 1992 (Table 3B). Even without considering additional use of imidazolinones in soybean, the exposure of weeds to these herbicides will be increasing in the coming years because of their use in other rotational crops such as corn.

Commercial sale of imidazolinone-resistant corn was initiated in 1993 by four seed companies (Pioneer Hi-Bred, Zeneca Seeds, Ciba Seeds, and Cenex/Land O'Lakes), mostly in the northern corn belt. About a half million hectares of imidazolinone-resistant seed were available for planting in the 1993 season with the prospect of increased availability in future years as well as development of additional imidazolinone-resistant hybrid varieties (87).[10,11,12]

Extending the use of imidazolinones to corn presents several potential problems in terms of weeds evolving

Table 3. Use of acetolactate synthase inhibiting herbicides 1990–1992, for A) each of the nine largest soybean producing states and B) all major soybean producing states.

State and herbicide	Area planted in soybean in 1992	Soybean area treated[a] 1990	1991	1992
	ha		%	
A. Usage by state				
Illinois	3 850 000			
Imazethapyr		9	26	28
Imazaquin		11	14	15
Chlorimuron		27	22	20
Iowa	3 360 000			
Imazethapyr		22	40	52
Imazaquin		11	3	NR[b]
Chlorimuron		20	15	16
Minnesota	2 230 000			
Imazethapyr		35	52	66
Imazaquin		NR	NR	1
Chlorimuron		NR	NR	NR
Indiana	1 840 000			
Imazethapyr		8	18	23
Imazaquin		14	20	19
Chlorimuron		32	25	26
Missouri	1 740 000			
Imazethapyr		7	13	42
Imazaquin		41	30	17
Chlorimuron		26	22	21
Ohio	1 520 000			
Imazethapyr		4	16	19
Imazaquin		14	13	19
Chlorimuron		35	33	29
Nebraska	1 010 000			
Imazethapyr		16	32	39
Imazaquin		12	11	12
Chlorimuron		16	13	14
South Dakota	930 000			
Imazethapyr		10	28	34
Imazaquin		NR	NR	NR
Chlorimuron		NR	NR	11
Kansas	770 000			
Imazethapyr		NR	11	16
Imazaquin		20	35	35
Chlorimuron		15	9	18
B. Usage for all soybean states[c]				
Imazethapyr		11	24	29
Imazaquin		16	15	18
Chlorimuron		20	17	17

[a]Source: (8), (9), and (14) for 1990, 1991, and 1992, respectively.

[b]Not reported.

[c]Area planted in soybean (million ha): 23.1 (1990); 22.3 (1991); and 21.2 (1992).

[8]Barrentine, W. L. 1993. Personal communication. Delta Res. and Ext. Ctr., Stoneville, MS 38776.

[9]Kendig, J. A. and M. S. DeFelice. 1994. ALS resistant cocklebur (*Xanthium strumarium* L.) in Missouri. Weed Sci. Soc. Am. Abstr. 34:12.

[10]Edwards, M. 1993. Personal communication. Pioneer Hi-Bred Int., Inc., P.O. Box 6500, West Des Moines, IA 50265.

[11]Greenwald, R. 1993. Personal communication. Zeneca Seeds, Des Moines, IA 50266.

[12]Christiansen, D. 1993. Personal communication. Ciba Seeds, Greensboro, NC 27419.

resistance. A substantial part of the soybean area in the northern corn belt is rotated with corn. Fifty-seven percent of the area planted to either soybean or corn in 1989 in the northern corn belt was used to grow the alternate crop in 1988 (32). In 1991–1992 corn and soybean were rotated on 54% of the crop area (17). Thus, a farmer who formerly rotated herbicides along with soybean-corn crop rotations now has the option to continuously use imidazolinones. Some of the area planted to continuous corn or corn rotated with crops other than soybeans, which formerly never encountered imidazolinones, now will be exposed. Corn and soybean have similar growing seasons and across most of the northern corn belt they have essentially the same spectrum of summer annual weeds. Species such as foxtails (*Setaria* spp.), velvetleaf (*Abutilon theophrasti* Medicus # ABUTH), cocklebur, pigweeds (*Amaranthus* spp.), common lambsquarters (*Chenopodium album* L. # CHEAL), and smartweeds (*Polygonum* spp.) are problem weeds of both crops. Thus, if imidazolinones are used extensively in corn-soybean rotations, the same populations of weeds will be exposed to the same herbicide chemistry year after year, increasing the probability of the evolution of herbicide-resistant weed biotypes. The situation is further exacerbated by the availability of sulfonylurea herbicides in soybean and corn. Chlorimuron {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} was applied to 17% (Table 3B) and thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid} to 7% of soybean crop area in 1992 (14). Two recently released sulfonylurea herbicides, nicosulfuron {2-[[[[4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide} and primisulfuron {2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]-amino]sulfonyl]benzoic acid}, were used to treat 8% of the corn area in 1992 (14).

Research is also underway to develop varieties of wheat, oilseed rape (*Brassica napus* L.) and tomato (*Lycopersicon esculentum* Mill.) resistant to ALS inhibitors (43, 48, 60, 63, 84). Already in many agricultural areas there are crops naturally resistant to at least one ALS inhibitor. With the prospect of increasing use of ALS-inhibiting herbicides we should expect the more extensive evolution of resistant weeds to follow quickly.

[13]Owen, M.D.K. 1993. Personal communication. Agronomy Dep., Iowa State Univ., Ames, IA 50011.

Analysis of herbicide mixtures recommended for imidazolinones in soybean/corn cropping. At present, imidazolinones are primarily used in soybean and are being extended into corn. Thus, we have analyzed the mixtures proposed for those two crops. As sulfonylurea and other ALS inhibitor use becomes more widespread, their mixtures should be evaluated using the same criteria. As imidazolinone-resistant cocklebur has been discovered in several locations, we have chosen to analyze the usefulness of the herbicide mixtures recommended by the manufacturer for lessening the likelihood of evolution of resistant populations of this weed. We posed the following rhetorical question: which, if any, of these mixtures might have prevented the evolution of imidazolinone-resistant populations of cocklebur? Cocklebur is an annual broadleaf weed commonly found in cultivated lands, pastures, along streams and rivers, and in waste places (44). Cocklebur is considered the most competitive weed of soybean in the southeastern U.S. (10). Each burr on the plant produces two heteromorphic seeds, with lower seeds having less dormancy than upper seeds (20, 44). Some seeds germinate promptly while others remain dormant and germinate months or years after maturity and dispersal (44). Cocklebur typically appears in fields throughout the growing season. Small plants can flower and set seed in the photoperiods of the early and late growing season.[8,13]

Cocklebur presents a difficult case for herbicide mixtures aimed at managing resistance for imazaquin and imazethapyr. Firstly, cocklebur is very sensitive to the imidazolinone herbicides used in soybean. Thus, these herbicides apply strong selection pressure for resistance. The recommended application rate for imazaquin in soybean is 140 g ai/ha (10). One-eighth that amount, 17 g/ha, is sufficient for control of cocklebur.[8] Imazethapyr controls cocklebur when applied to soil (65 to 75% control) or leaves (85 to 95% control) (11). Secondly, both imazaquin and imazethapyr are sufficiently active in the soil to provide season-long control of cocklebur (as well as other weeds). The manufacturer recommends waiting 11 mo before rotating corn, barley (*Hordeum vulgare* L.), peanut (*Arachis hypogaea* L.), or oat (*Avena sativa* L.) with soybean treated with imazaquin (12). For imazethapyr the recommended waiting periods are 9.5 mo for corn and peanut and 18 mo for most other crops (12). This suggests that these herbicides have residual lifetimes sufficient to remain effective against particularly susceptible crops and weeds for long durations. Cocklebur can germinate, flower, and set seed throughout the growing season, and

Table 4. Manufacturer's recommendations for broadleaf herbicide mixtures with imidazolinones to reduce the risk of weed resistance in soybean[a].

Imidazolinone	Recommended mixing partner(s)	Characteristics of mixing partner(s) for control of cocklebur
Imazethapyr	acifluorfen, lactofen, fomesafen	These herbicides only have activity for very small cocklebur (3 to 4 leaf stage), and efficacy is less than imidazolinones. All are short residual, contact herbicides requiring multiple applications for season-long cocklebur control.
Imazethapyr	metribuzin	Metribuzin provides only partial control of cocklebur
Imazethapyr	linuron	Linuron provides only partial control of cocklebur
Imazethapyr and imazaquin	glyphosate, paraquat	Glyphosate and paraquat are non-selective, short residual, post weed emergence herbicides. They effectively control cocklebur but multiple applications would be required for season-long control.
Imazaquin	clomazone	Clomazone is primarily a grass herbicide with only partial control of cocklebur.

[a]Mixing partner recommendations from (7).

after the crop has been harvested. By remaining active throughout and beyond the growing season, the imidazolinones can select for resistant, newly emerging cocklebur biotypes for many months after application. Thus, an effective mixing partner for the imidazolinones must provide equally effective season-long control of cocklebur.

Recommended mixing partners for soybean. Several of the herbicide mixing partners recommended by the manufacturer provide only partial control of cocklebur and would only delay resistant populations from evolving if they severely inhibit cocklebur and if they have the same duration of residual activity as the imidazolinone (Table 4). These include metribuzin [4-amino-6-(1,1-dimethyl(ethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one], linuron [*N'*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea], and clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone}. All three have shorter effective persistence either due to shorter actual half-life compared to the imidazolinones, or because they do not inhibit cocklebur as much as the imidazolinones. Thus, cocklebur germinating mid and late season are effectively controlled only in contact with the ALS inhibitor. Acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}, lactofen {(±)-2-ethoxy-1-methyl-2-oxoethyl-5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate}, and fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy-*N*-(methylsulfonyl)-2-nitrobenzamide} are contact herbicides of relatively short persistence and do not control cocklebur as well as the imidazolinones. They are effective only for very small cocklebur (3- to 4-leaf stage). Glyphosate [*N*-(phosphonomethyl)glycine] and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) are non-selective herbicides requiring special application methods to protect crops from damage. Both herbicides are strongly and rapidly adsorbed to soil, rendering them biologically inactive. While glyphosate and paraquat control cocklebur, their inclusion in a cocklebur resistance prevention program requires that they be applied whenever the weed is observed in the field. As cocklebur has staggered and extended germination patterns, this becomes impractical. Thus, it appears that none of the mixing partners presently promoted for use with imazaquin and imazethapyr in soybean can effectively prevent resistant biotypes of cocklebur from evolving and spreading.

The manufacturer of the imidazolinones is now recommending late-season use of bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide], the major herbicide replaced by the ALS-inhibitor, to control cocklebur in the southern, long season soybean areas.[5] This strategy, if adopted quickly by farmers might both contain and set back resistance so that the imidazolinones could remain effective for a longer period. This will be effective only if bentazon can penetrate the soybean canopy to eliminate all late season germinators. Otherwise, resistant individuals will be left behind.

Recommended mixing partners for corn. Various mixing partners recommended by the manufacturer for use in imidazolinone-resistant corn are presented in Table 5. Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile), 2,4-D [(2,4-dichlorophenoxy)acetic acid], and dicamba (3,6-dichloro-2-methoxybenzoic acid), when used at low rates in most environments, are effective for control of cocklebur but are short-persistence herbicides. Only atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] matches the efficacy and persistence characteristics (when used at full field rates) of imazethapyr and could

Table 5. Manufacturer's recommendations for broadleaf herbicide mixtures with imazethapyr to reduce the risk of weed resistance in imidazolinone resistant corn[a].

Recommended mixing partner	Characteristics of mixing partner for control of cocklebur
Atrazine	Has similar persistence and efficacy as imazethapyr for cocklebur, but at recommended rate of application (555 g ai/ha) would have little persistence.
Bromoxynil	A contact herbicide that degrades rapidly. It effectively controls cocklebur but multiple applications would be required for season-long control.
Dicamba	A systemic herbicide with limited persistence, that effectively controls cocklebur. Multiple applications would be required for season-long control.
2,4-D	A postemergence, short residual, systemic herbicide, that provides effective control of cocklebur. Multiple applications would be required for season-long control.

[a]Mixing partner recommendations from (7, 12).

delay the evolution of resistant populations. However, at the recommended application rate (555 g ai/ha) with imazethapyr, atrazine would have shorter-lived field activity than the normally used rate, which is two to four times higher. Thus, atrazine might not control cocklebur germinating late in the season.

Analysis of mixtures proposed for sulfonylureas in winter wheat. Much of the wheat cultivated around the world is grown in areas where few other crops can be grown, leading to extensive monocultures. Increases in yields have been largely due to breeding shorter, high harvest index wheats that respond to increased fertilization, and/or growing long season winter wheats that continue growing in the field for ca. 10 mo. Cultivating such wheats requires herbicides to suppress weeds, as weeds compete with the newer, shorter, wheat cultivars, or come up and compete in spring in the winter wheats. For over 40 yr, 2,4-D controlled many broadleaf weeds, with a variety of herbicides providing a modicum of grass control. Postemergence application of 2,4-D has short soil persistence and often allowed a flush of susceptible weeds to go to seed either before application, or after the herbicide dissipated. By letting susceptible weed seed persist in the seed bank, selection pressure for resistance has remained low. With the exception of a recent minor case (85), this low selection pressure may explain in part why no major outbreaks of 2,4-D resistant weeds have been reported.

The advent of highly persistent sulfonylurea herbicides such as chlorsulfuron and the slightly less persistent metsulfuron {2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid} provided high levels of control for a broad spectrum of weeds, including some grasses. The users realized superior weed control (though not always higher yields) and competitive pricing brought about rapid acceptance of chlorsulfuron. Soon after registration on wheat in 1982, chlorsulfuron replaced about 40% of the 2,4-D previously used in U.S. winter wheat (3). By 1988 18.5% of the total area of the U.S. winter wheat crop was treated with chlorsulfuron (slightly more than 2 million ha) compared to 9.2% for 2,4-D (5). Target site resistance to chlorsulfuron rapidly evolved after 4 or 5 yr of continuous use in biotypes of prickly lettuce, kochia, and Russian thistle (*Salsola iberica* Sennen & Pau # SASKR) (73). The manufacturer of chlorsulfuron quickly came up with a series of resistance management strategies for affected areas (4, 61). The strategies included: a) no preemergence, only postemergence use; b) application no more than once in 4 yr; c) fallow use was proscribed; and d) use at lower rates in tank mixes with other herbicides. Recommendations a–c and use at lower rates all decrease selection pressure for evolution of target-site resistance and their utility is self-evident. The question we address here is whether mixing less vulnerable herbicides with chlorsulfuron and other ALS inhibitors will affect the rate of evolution of resistance.

Two types of resistance to chlorsulfuron have appeared in wheat; a) target site resistance with a modified ALS (24, 71, 72), and b) metabolic resistance characterized by a greatly enhanced rate of degradation of the herbicide (24, 25, 27). Both types have even evolved in different biotypes of the same weed (22).

All of the mixture partners proposed for chlorsulfuron have much lower biological persistence than chlorsulfuron (Table 6). They are dissipated within 4 to 6 wk of application whereas chlorsulfuron provides season long control, often lasting into following seasons, depending mainly on soil pH (21). Thus, none of the proposed partners meets the equal persistence criterion (except for weeds germinating in a single flush). The persistence problem has partially been met by the recent introduction of sulfonylureas with much shorter persistence. Some may persist longer than some of the mixing partners. Data are not available to compare rates of degradation in the same soil under the same conditions. In any case, the short-residual ALS-inhibitors introduced for winter wheat have not gained wide acceptance and are applied on only 3 to 6% of planted area (14).

Other sulfonylureas have been proposed as mixing part-

Table 6. Manufacturer's recommendations of herbicide mixtures with chlorsulfuron for resistance management in winter wheat[a].

Recommended mixing partner(s)[b]	Characteristics of mixing partner(s) for resistance management of chlorsulfuron[c]
2,4-D	A short residual systemic herbicide. Timing of application important for effective control of kochia but generally not as effective as chlorsulfuron, especially throughout the season.
Metribuzin	A short residual postemergence herbicide. Can provide good control for kochia but not throughout the season, and prickly lettuce but not in all areas throughout the season. Only partially controls Russian thistle.
MCPA	A short residual contact herbicide. Does not control Russian thistle, kochia, or prickly lettuce as well as chlorsulfuron and not throughout the season.
Bromoxynil	A short residual contact herbicide. At some locations can give excellent control of kochia, although not throughout the season. At other locations it is rated not nearly as effective as chlorsulfuron. Control of Russian thistle only fair.
Bromoxynil + MCPA	Both are short residual contact herbicides. Will not control kochia, Russian thistle, or prickly lettuce as well as chlorsulfuron throughout the season.
Dicamba	A short residual, contact herbicide. Not as effective as chlorsulfuron for control of kochia throughout the season. Only fair control of Russian thistle.
2,4-D + clopyralid	Both are postemergence systemic herbicides that dissipate more rapidly than chlorsulfuron. Clopyralid provides only partial control of kochia and Russian thistle. Mixture does not add to effectiveness of 2,4-D for target weeds.
Diuron	Diuron has a much narrower weed spectrum compared to chlorsulfuron. Kochia, prickly lettuce, and Russian thistle are not as effectively controlled as with chlorsulfuron.

[a]Mixing partner recommendations from (16).

[b]Clopyralid, (3,6-dichloro-2-pyridinecarboxylic acid); diuron, *N'*-(3,4-dichlorophenyl)-*N,N*-dimethylurea).

[c]Evaluations from various sources in infested areas.

ners but this does not meet the "different target" criterion, while some mixture partners (2,4-D, MCPA [(4-chloro-2-methylphenoxy)acetic acid], dicamba, bromoxynil) meet it. None of the mixing partners with different modes of action have the same spectrum of weeds controlled over the whole season (Table 6). Thus, weeds such as kochia, prickly lettuce, and Russian thistle would often be biologically "unaware" of a mixture partner, so that major weeds known to evolve resistance will continue to do so despite the mixture. Still, the rate of evolution may be somewhat dampened due to early season control by the vulnerable herbicide.

[14]J. Gressel, L. Segel, and M. Mangel, manuscript in preparation.

Evolution of metabolic resistance in weeds. The above strategies for wheat and soybean/corn almost solely address the evolution of target site resistance. There is a possibility that mixtures would not preclude the evolution of metabolic resistance. This could be prevented in corn or soybean by using a partner that cannot be degraded by the same enzyme type as degrades the ALS inhibitors. This is not the case in wheat, where in all documented cases herbicides are degraded by monooxygenases (34), unless another metabolic degradation system is activated by a protectant (68). If broadleaf weeds can evolve enhanced degradation by monooxygenases as have grass weeds (25, 27, 51), then there is reason to believe that the proposed mixtures will be subject to evolution of a similar resistance.

Reducing application rates of herbicides in mixtures lowers selection pressure for the evolution of target site resistance and has probably enhanced the rate of evolution of metabolic resistance, as has happened with insecticides (35).[14] Resistance derived from multiple genes or by gene amplification can evolve quickly only if low rates are used, which selects for incrementally added gene doses. Insects and fungi have evolved metabolic pesticide resistances under either polygenic control or due to gene amplification (cf. 23, 67). Similarly, mammalian cancer cells have evolved drug resistances that are also due to gene amplification. Thus, the lower rates usable in mixtures of herbicides can be expected to decrease the rate of evolution of target site resistance and enhance the rate of metabolic weed resistance (35).

Compliance with recommendations to use mixtures. Assuming there were mixtures available that could manage resistance, there is nothing that now requires a farmer to use them. Although the manufacturer of imazethapyr is strongly advocating mixtures for resistance management, 72% of the soybean farmers surveyed following the 1992 season indicated that they applied this herbicide alone and not in mixture (Figure 2A). Twenty-three percent applied imazethapyr with a grass herbicide as a complementary mixing partner to increase the spectrum of weeds controlled, rather than to control the weeds most likely to evolve resistance. Only 5% of the farmers surveyed used a broadleaf mixing partner that might have some delaying effect on the evolution of resistance in a weed like cocklebur.

In 1992, 29% of soybean farmers surveyed in Iowa and Illinois (the two largest soybean producing states) reported using imazaquin or imazethapyr alone or in combination with other ALS inhibitors (Figure 2B). Thirty-nine percent of farmers using the imidazolinones tank-mixed them with

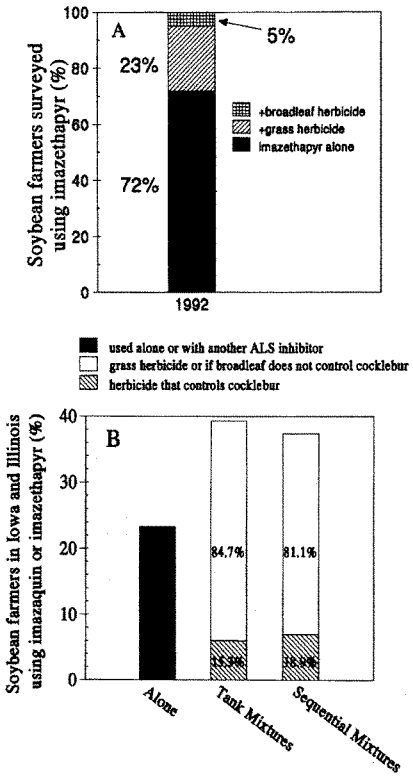


Figure 2. Usage of mixtures in soybean. A. The percentage of U.S. soybean farmers, surveyed following the 1992 season, using imazethapyr alone, with a grass herbicide, or with a broadleaf herbicide. Percentages are based on 1069 soybean farmers that reported using imazethapyr out of 7073 soybean farmers surveyed. Source: (15). B. The percentage of soybean farmers in Iowa and Illinois, surveyed following the 1992 season, using imazaquin or imazethapyr either alone, in tank-mix, or sequentially with other herbicides. Of the 1639 farmers surveyed in Iowa and Illinois, 481 (29.3%) used imazaquin or imazethapyr. Source: (15).

a non-ALS inhibitor, while 37% used a sequential treatment with a non-ALS inhibitor. Over 80% of farmers tank mixing or sequentially mixing chose mixing partners that can not control cocklebur (Figure 2B). The specific herbicides used with the imidazolinones were similar whether farmers used a tank mix or sequential applications. Seventy-five percent of farmers using tank-mixes choose dinitroaniline herbicides as the partner, while 61% of farmers used these herbicides in sequence with the imidazolinones. The dinitroanilines primarily control grass weeds and have minimal activity on cocklebur. In only 15% of the cases using tank-mixes and 19% of the sequential applications were herbicides used that have high activity for cocklebur (Figure 2B). These were all short residual herbicides, with glyphosate being the most popular. In summary, very few soybean farmers using imidazolinone herbicides are following the herbicide-resistance weed management mixture recommendations of the manufacturers.

In winter wheat, chlorsulfuron has been removed from market areas with the most severe resistance problems. In areas where chlorsulfuron continues to be sold, many farmers prefer it because of the weed free fields that result. In 1992, 14% of total U.S. winter wheat area, or 42% of the winter wheat area treated with herbicides, was treated with chlorsulfuron. This accounted for slightly over 2 million ha, an area equal to that treated with 2,4-D (14). An additional 7% of total winter wheat area was treated with another long residual sulfonylurea, metsulfuron, while two short residual sulfonylureas, thifensulfuron and tribenuron {2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid}, were applied to 3 to 6% of planted area (14). Over 60% of winter wheat growers surveyed after the 1992 season that used herbicides applied at least one sulfonylurea herbicide (15). Label requirements in wheat for mixing more highly persistent sulfonylureas are often ignored, which has probably led to additional cases of resistance. Forty-six percent of the farmers surveyed applying chlorsulfuron to winter wheat in 1992 used this herbicide alone or in tank mix with metsulfuron, a sulfonylurea with only slightly less persistence (Figure 3). There are also reports that many farmers from areas where chlorosulfuron is proscribed purchase the herbicide elsewhere.

Thus, it appears that companies believing that their herbicides should be used in mixture for resistance management are having a difficult time convincing farmers to adopt this strategy. Based on present use patterns among growers, manufacturers would have to market resistance-prone herbicides only as premixes, to obtain compliance, assuming satisfactory mixture partners for resistance management were identified.

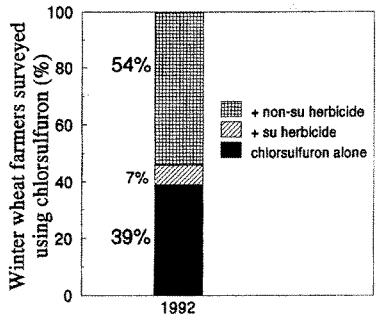


Figure 3. The percentage of winter wheat farmers surveyed following the 1992 season using chlorsulfuron alone, with another sulfonylurea herbicide, or with a non-sulfonylurea herbicide. Percentages are based on 205 winter wheat farmers who reported using chlorsulfuron out of 617 farmers surveyed who applied a herbicide. Source: (15).

CONCLUDING REMARKS

While the proposed mixing strategies may have some value for general weed control, the ones discussed do not meet the criteria for resistance management in preventing further evolution of resistant cocklebur or kochia as well as other weeds with similar properties. Mixtures have already broken down in Europe. Atrazine-resistant weeds appeared when fenuron (*N,N*-dimethyl-*N'*-phenylurea), a short residual herbicide, was used together with atrazine. Initially, only half the populations were resistant due to replenishment of susceptible plants from the seed bank. Repeated use of the atrazine-fenuron mixture enriched the resistant population to near 100%.[15]

Mixtures may theoretically be constructive tools for managing resistance when they meet the criteria listed. Still, it is questionable whether the problems of finding partners with the proper efficacy and persistence along with convincing farmers to use mixtures that increase costs without immediate weed control benefits can be overcome. If tenable mixtures could be found, they might have to be marketed only as premixes, as is done with some vulnerable fungicides. The herbicide mixtures presently recommended do not seem to have the properties to prevent or in some cases significantly delay the evolution of resistant weeds.

The possible lack of a major fitness difference between ALS level resistant and susceptible biotypes also argues for caution in use of these chemicals. We find it troubling that herbicide mixtures are being represented by some as a primary means to avoid or drastically delay ALS-inhibitor resistance problems. We believe that the marketing strategies leading to increased use of ALS-inhibiting herbicides, the development of imidazolinone-resistant corn cultivars and the development of other crop cultivars with resistance at the level of ALS are together ill-founded. This will likely result in even more widespread ALS-inhibitor resistance in weeds, requiring drastic steps to remediate the problem. The expansion of use of these herbicides, in the long-term serves neither the interests of the chemical industry nor of the agricultural community, which depends on industry. One must think beyond herbicides and short-term economics to retain excellent but resistance-prone chemistries such as the ALS inhibitors.

Now that ALS-resistant weeds have evolved in these cropping systems, mixtures containing a few percent of resistant and susceptible weed seeds can be used in controlled experiments in the field to rapidly evaluate the efficacy of various herbicide mixing strategies alongside other management strategies. Such experiments can be carried out in normally used cropping systems. This would provide some real data to evaluate mixtures under field conditions rather than relying too much on theoretical considerations.

[15]Ammon, H. U. 1994. Personal communication. Swiss Federal Res. Stn.-Agronomy, Zurich-Reckenholz.

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Reviews

Herbicide-Resistant Weeds: Management Tactics and Practices[1]

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Abstract: In input-intensive cropping systems around the world, farmers rarely proactively manage weeds to prevent or delay the selection for herbicide resistance. Farmers usually increase the adoption of integrated weed management practices only after herbicide resistance has evolved, although herbicides continue to be the dominant method of weed control. Intergroup herbicide resistance in various weed species has been the main impetus for changes in management practices and adoption of cropping systems that reduce selection for resistance. The effectiveness and adoption of herbicide and nonherbicide tactics and practices for the proactive and reactive management of herbicide-resistant (HR) weeds are reviewed. Herbicide tactics include sequences and rotations, mixtures, application rates, site-specific application, and use of HR crops. Nonherbicide weed-management practices or nonselective herbicides applied preplant or in crop, integrated with less-frequent selective herbicide use in diversified cropping systems, have mitigated the evolution, spread, and economic impact of HR weeds.

Additional index words: Herbicide resistance, integrated weed management.

Abbreviations: ACCase, acetyl-CoA carboxylase; ALS, acetolactate synthase; APP, aryloxyphenoxypropionate; CHD, cyclohexanedione; DSS, decision-support system; EPSPS, enolpyruvylshikimate-3-phosphate synthase; HR, herbicide resistant; HS, herbicide susceptible; IWM, integrated weed management.

INTRODUCTION

The main risk factors for the evolution of HR weeds are: (a) recurrent application of highly efficacious herbicides with the same site of action; (b) annual weed species that occur at high population densities, are widely distributed, genetically variable, prolific seed producers, and have efficient gene (seed or pollen) dissemination; and (c) simple cropping systems that favor a few dominant weed species (Owen 2001a; Thill and Lemerle 2001). Globally, the most economically important HR weeds include rigid (annual) ryegrass (*Lolium rigidum* Gaudin), wild oat (*Avena fatua* L.), *Amaranthus* spp. (redroot pigweed, *A. retroflexus* L.; smooth pigweed, *A. hybridus* L.; common waterhemp, *A. rudis* Sauer; and tall waterhemp, *A. tuberculatus* (Moq.) J.D. Sauer), common lambsquarters (*Chenopodium album* L.), green foxtail [*Setaria viridis* (L.) Beauv.], barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], goosegrass [*Eleusine indica* (L.) Gaertn.], kochia [*Kochia scoparia* (L.) Schrad.], horseweed [*Conzya canadensis* (L.) Cronq.], and blackgrass (*Alopecurus myosuroides* Huds.) (Heap 2005). For the majority of HR weed biotypes, herbicide resistance is target-site based, conferred by a single, major (i.e., large phenotypic effect) gene with a high degree of dominance (Powles et al. 1997). This mode of inheritance favors the rapid evolution of weed resistance to herbicides applied at registered rates.

In high-input cropping systems around the world, farmers are reluctant to proactively manage weeds to prevent or delay the selection for herbicide resistance. The cost and effort of preventing/delaying resistance to many herbicides are widely perceived or estimated to be the same as that of managing HR weeds, and therefore farmers often do not change their weed management program until resistance has occurred. The lack of proactive management of the evolution of HR weed populations may be due to farmers' primary interest in optimizing short-term economic returns, or inability to assess the economic risks associated with HR weeds (Rotteveel et al. 1997).

Low adoption of resistance–avoidance tactics may also be due to the lack of alternative herbicide groups (defined by site of action) to control the target weeds, or

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Table 1. Use of integrated weed management practices by Western Australian grain farmers in 2000 (n = 132) (adapted from Llewellyn et al. 2004).

Practice[a]	Farmer adoption			Expected efficacy[c]
	HR[b]	no HR	All	
	%			
Stubble burning	85	66	76	47 ± 19
Weed seed catching	10	2	7	57 ± 15
Tillage	49	49	46	39 ± 22/49 ± 21
Autumn tickle (preplant tillage)	57	26	44	
Delayed planting	53	35	46	55 ± 23
Double knock	62	49	57	64 ± 21
Crop topping	44	11	30	62 ± 17
Green manuring	21	11	17	74 ± 19
Crop cut for hay	31	49	39	
Spray topping	95	94	94	
High wheat seeding rate	57	54	56	28 ± 17/35 ± 19
Trifluralin[d]				67 ± 14

[a] Double knock, crop topping, and spray topping are the use of a nonselective herbicide applied: preplant (followed by another nonselective herbicide or tillage), to annual legumes at postanthesis weed growth stage, and to pastures, respectively, to reduce weed seed production.

[b] HR: farmers with herbicide resistance (n = 77) vs. no resistance (n = 55).

[c] Efficacy expected by farmers for rigid ryegrass (*Lolium rigidum* Gaudin) control ± standard deviation; tillage, high seeding rate: difference among nonusers and users, respectively.

[d] Included for comparison.

unrealistic expectations that new herbicide technology will continually be forthcoming (Llewellyn et al. 2002). However, herbicides should be viewed as a nonrenewable resource. With the cost of discovering, developing, and marketing a novel herbicide at approximately United States (U.S.) $150 to $180 million in 2005 (D. Porter, personal communication), farmers cannot expect many compounds with novel sites of action to be commercialized in the near future.

Additionally, a lack of information on the impact of management tactics and practices on selection of herbicide resistance may limit a farmer's ability to delay resistance. How long herbicide resistance can be delayed by implementing a comprehensive integrated weed-management (IWM) program is uncertain. Moreover, recommendations to farmers to delay or prevent herbicide resistance are often similar to those recommended for managing resistance, thus discouraging the adoption of prevention tactics. Socioeconomic factors in developed countries, such as farmer demographics, increasing size of farms with concomitant limited labor and time availability, high percentage of leased land by renters with a general lack of awareness of previous herbicide history or reduced motivation for long-term stewardship, and preference for annual cropping systems based on lifestyle choice and cash flow, reinforces a heavy reliance on herbicides as the dominant method of weed control (Friesen et al. 2000).

Farmers usually increase the adoption of IWM practices only after herbicide resistance has evolved (Beckie and Gill, 2006). Populations of a number of HR grass weed biotypes threaten cereal grain production in different areas of the world. Cross-resistance (a single resistance mechanism conferred by one or more genes) and multiple resistance (two or more resistance mechanisms) in weed species have often been the main impetus for the utilization of a greater number of IWM practices in cropping systems (Powles et al. 1997, 2000). For example, farmers in Western Australia with infestations of HR rigid ryegrass practice weed seed catching at harvest more frequently than those with no resistance (Table 1). Farmers with resistance used an average of 8.4 IWM practices, significantly more than farmers with no resistance (mean of 6.6) (Llewellyn et al. 2004).

Prevention can cost significantly less than dealing with resistance once it fully develops, where intergroup herbicide resistance occurs, or where few alternative herbicides are available (Orson 1999). The greatest direct cost of herbicide resistance to the farmer can occur during the first year of poor weed control and consequent yield loss (Peterson 1999). Populations of weeds with high fecundity potential, such as rigid ryegrass, can increase rapidly after control failures caused by resistance. To manage resistance, farmers first use alternative herbicides (i.e., addition of a tank-mix partner or rotating to a herbicide with a different site of action). In some situations, herbicides that selected for resistance may continue to be used because of their cost-effective (i.e., economical) control of non-HR weed species (e.g., triazines or glyphosate applied to land with triazine- or glyphosate-HR biotypes, respectively). The addition of a herbicide to control the HR weed biotype, however, will

increase costs to the farmer (Peterson 1999). The short-term cost of resistance is minimal if alternative herbicides are available, such as those for control of many biotypes resistant to phenoxy or photosystem I-disrupting herbicides (Beckie et al. 2001b). In contrast, there may be a limited number of herbicide options for control of some intergroup-HR biotypes, and those that are available usually increase costs. For example, most or all alternative herbicides to control intergroup-HR biotypes of wild oat or green foxtail in the northern Great Plains increase costs to farmers (Beckie et al. 1999b, 1999c). Management of glyphosate-HR horseweed in conservation-tillage systems in the North Delta region of the United States requires a phenoxy herbicide and one or two residual herbicides. As a consequence of this additional herbicide cost (U.S. $16 to $62/ha), conservation tillage has dropped by about 50% in cotton (*Gossypium hirsutum* L.) and 30% overall (Steckel et al. 2005).

The prime strategy for managing herbicide resistance in weeds is to reduce the selection pressure for resistance evolution by any one selecting agent, while maintaining adequate weed control. Selection pressure has the greatest impact on herbicide-resistance evolution and is a factor that farmers can control. Selection pressure imposed by a herbicide is the product of selection intensity (efficacy) and selection duration (persistence in soil) (Putwain 1982). Herbicides applied in crop generally result in the greatest selection pressure compared with other application timings. Selection pressure against a weed population over time, resulting in increasing frequency of HR individuals that collectively possess one or more resistance mechanisms, is a function of frequency of application. Mathematically, the relative selection pressure of a herbicide on a target weed species in a population has been defined as the proportion of HR plants divided by the proportion of herbicide-susceptible (HS) plants that remain after exposure to the herbicide (Gressel and Segel 1982). These proportions are equal to one minus the effective kill, defined by seed yield reduction (Beckie and Morrison 1993; Gressel and Segel 1982). For example, if seed production of HR and HS biotypes is reduced by 42 and 99%, respectively, relative selection pressure is estimated to be $(1 - 0.42)/(1 - 0.99) = (0.58)/(0.01) = 58$. By definition, the selection pressure can only be reduced by lowering the effective kill of HS plants or increasing the effective kill of HR plants. No selection pressure is exerted when HS and HR genotypes are controlled equally. Diversification of selection pressures on weed populations, such as varying the type and timing of herbicide application (e.g., selective or nonselective herbicides applied preplant, in crop, preharvest, or postharvest), integrating cultural or mechanical weed management practices with reduced herbicide use, and diversifying the cropping system as a whole, is required to reduce the selection pressure of any one selecting agent (Boerboom 1999).

In this review, tactics and practices to effectively delay or manage HR weeds in input-intensive cropping systems worldwide are summarized. Herbicide-based tactics are emphasized, because herbicides will continue to be the dominant weed-control tool in these cropping systems during the forseeable future. Nonherbicide tactics and practices that have been proven effective in managing HR weeds are outlined. Examples are provided to illustrate the impact of herbicide and nonherbicide tactics on the successful proactive and reactive management of HR weeds.

HERBICIDE TACTICS

A herbicide sequence is defined as two or more applications of herbicides with different sites of action within one crop, whereas herbicide rotation is the application of herbicides with different sites of action to multiple crops over multiple growing seasons in a field. Herbicide sequences, rotations, or mixtures generally have the greatest effect in delaying resistance when the mechanism conferring resistance is target-site based, the target weed species are highly self-pollinated, and seed spread is restricted (Beckie et al. 2001b; Wrubel and Gressel 1994). Multiple resistance can evolve within a weed population through a change in selection history (usually sequential selection), through selection of multiple mechanisms by a single herbicide, or through outcrossing among individuals containing different resistance mechanisms (Hall et al. 1994; Preston and Mallory-Smith 2001). Based on a compounded resistance frequency model, the probability of HR mutants with multiple mechanisms of resistance (target-site based) in an unselected population is the product of the probabilities of resistance to each affected herbicide site of action and thus is rare (Wrubel and Gressel 1994). However, frequent use of herbicides in a field over time can enrich HR populations with different resistance mechanisms. Outcrossing among plants, such as *Lolium* spp. or blackgrass, in close proximity that possess different HR mechanisms can result in multiple-HR progeny. Spreading HR seed within and among fields can also aid this process.

Herbicide Sequences and Rotations. *Adoption.* Performance and cost of herbicides usually rank higher than site of action when farmers select a herbicide. The lack of suitable herbicide options associated with crop rotation can be an impediment to herbicide group rotation (Bourgeois et al. 1997b; Légère et al. 2000). The level of adoption of herbicide group rotation for resistance management has increased markedly during the past decade in Canada and Australia. There is little information on the adoption of this tactic in other countries. In western Canada in 1998, fewer than 50% of farmers practiced herbicide group rotation, even though awareness was high (Beckie et al. 1999a). By 2003, 70 (Saskatchewan) to 90% (Manitoba) of farmers claimed to rotate herbicides by site of action (H. Beckie, unpublished data). In 2005, over half of the herbicide products sold in Canada had resistance management labeling, which includes group identification symbols on the label and guidelines for resistance management tactics in the use directions (N. Malik, personal communication). The guidelines were a joint effort between the Pest Management Regulatory Agency (PMRA 1999) in Canada and the U.S. Environmental Protection Agency (2001). By 1998 in Australia, the adoption rate of herbicide group rotation was 85%, attributed largely to site-of-action labeling on herbicide containers (Shaner et al. 1999). It is the most common herbicide resistance management tactic cited by farmers in survey questionnaires conducted in Australia (Shaner et al. 1999) and Canada (H. Beckie, unpublished data). A prerequisite for herbicide group rotation is keeping field records of herbicides used each year. Software packages of crop and herbicide rotation planners are available in many jurisdictions, which facilitate record keeping and can flag high-risk herbicide practices, such as repeated use of herbicides with the same site of action.

Mitigating herbicide resistance risk. Evolution of target-site resistance in weed biotypes is attributed to frequent use of herbicides of the same site of action and their propensity to select for HR biotypes (Beckie et al. 2001a; LeBaron and McFarland 1990). Knowledge of resistance risk could be an incentive for farmers to practice herbicide sequences or rotations to delay the rate of evolution of resistance. The ease of selection for HR biotypes is governed by several factors. As described previously, the selection pressure (efficacy and persistence) imposed on the target weed species by a herbicide is the most important factor affecting the rate of evolution of resistance. The slow evolution of resistance in weed biotypes to phenoxy herbicides, first introduced in 1946, has been partially attributed to relatively low selection pressure (Coupland 1994). Similarly, relatively low efficacy of trifluralin, a dinitroaniline herbicide, on rigid ryegrass has been cited as one reason for relatively slow evolution of resistance (Table 1). In a 1998 Western Australian field survey of rigid ryegrass, population densities were unrelated to herbicide resistance, suggesting the availability of alternative herbicides, particularly trifluralin, to control HR rigid ryegrass (Llewellyn and Powles 2001).

Nonpersistent herbicides generally exert less selection pressure than those that control successive flushes of germinating weeds throughout the growing season. The contribution of persistence to selection pressure, however, depends on timing of herbicide application and the germination characteristics of the target species in a geographic region. The soil residual activity of herbicides did not strongly influence selection pressure on wild oat in a competitive crop (canola, *Brassica napus* L.) in western Canada (Beckie and Holm 2002). The selection pressure exerted on wild oat by residual herbicides was the same as or lower than that of nonresidual herbicides. In the relatively short growing season in the northern Great Plains, few wild oat plants may emerge after postemergence application of a nonresidual herbicide and produce viable seeds in a competitive crop. In other agroecoregions, herbicide persistence in soil can have a much greater effect on selection pressure.

Whereas a single mutation can confer resistance to single site-of-action herbicides, multiple mutations within a plant are often needed to confer resistance to herbicides with more than one site of action, such as chloracetamide herbicides (Foes et al. 1998). As indicated previously, individuals in an unselected population with multiple mutations for resistance generally would be rare (Preston and Mallory-Smith 2001; Wrubel and Gressel 1994). The frequency of HR alleles in unselected populations defines the starting point for resistance evolution, and thus impacts the length of time for resistance to evolve to noticeable levels. An unusually low rate of mutation of the locus conferring resistance, or alternatively few fit mutations, are speculated to contribute to the slow evolution of resistance to phenoxys and other herbicides, such as glyphosate (Gressel 1999; Jasieniuk et al. 1995). Fit mutations are more probable for noncompetitive inhibitors of target-site enzymes such as acetyl-CoA carboxylase (ACCase, EC 6.4.1.2) and acetolactate synthase (ALS, EC 4.1.3.18), where the herbicide binding site is different from the active site. The probability of finding an initial HR mutant in an unselected population increases with an increase in the number of

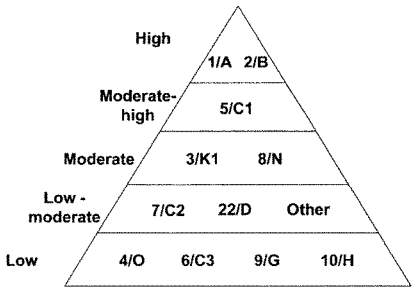


Figure 1. Classification of herbicide site of action by risk of selection for target-site resistance (high ≤ 10; moderate = 11–20; low >20 applications (H. Beckie and L. Hall, unpublished data); "Other": insufficient information to definitively categorize as low or moderate risk. Numerical (Weed Science Society of America) and alphabetical (Herbicide Resistance Action Committee) herbicide groups are described in Mallory-Smith and Retzinger (2003) or Heap (2005).

types of functional mutations (Murray et al. 1996). There are at least five different point mutations in each of the ACCase and ALS target sites in HR weed biotypes, each conferring a different cross-resistance pattern and level of resistance (Délye and Michel 2005; Gressel 2002). Indeed, the frequency of target-site–based ALS inhibitor-HR individuals in untreated populations of rigid ryegrass was found to be relatively high, ranging from 10^{-5} to 10^{-4} (Preston and Powles 2002a). In contrast, most mutations conferring resistance to glyphosate, a competitive inhibitor of enolpyruvylshikimate-3-phosphate synthase (EPSPS, EC 2.5.1.19), and glufosinate, a competitive inhibitor of glutamine synthetase (EC 2.7.7.42), are believed to be lethal.

The risk of target-site resistance, defined by the mean number of applications before resistance is detected, varies by herbicide group (Figure 1). This approach of risk assessment assumes that a particular herbicide site of action is effective for a set number of applications before the onset of target-site resistance. The use of herbicide "shots" is appropriate in economic models and farm-management decision aids (Diggle and Neve 2001). Anecdotal information, namely, field histories of herbicide use, usually is used for assessing the risk of selecting for resistance based on an herbicide's site of action. Only one long-term experiment has examined the effect of frequency of herbicide use on the evolution of resistance. In a large-plot field experiment conducted from 1979 to 1998, resistance in wild oat to triallate occurred after 18 yr where the herbicide was applied annually in continuous spring wheat (*Triticum aestivum* L.), but not where it was applied 10 times in a wheat–fallow rotation over the same period (Beckie and Jana 2000).

It is widely agreed that ACCase and ALS inhibitor herbicides pose a high risk for selecting HR biotypes relative to herbicides from other groups (Dellow et al. 1997; Gressel 1997; Heap 1999; LeBaron and McFarland 1990; Monjardino et al. 2003). High-risk herbicides should be applied less often in sequences or rotations than lower-risk herbicides. At a minimum, use of high-risk herbicides in consecutive years in a field should be avoided. In sequences, lower-risk, nonselective herbicides, such as photosystem-I electron diverters (paraquat, diquat) or EPSPS inhibitor (glyphosate) should be used preplant to reduce the number of weeds selected with in-crop herbicides that pose a higher risk. Ideally, high-risk herbicides should not be used in fields with high weed densities, because the number of HR mutants is proportional to population size (Jasieniuk et al. 1996).

Nonselective herbicides, such as paraquat, are commonly applied at the postanthesis stage of rigid ryegrass in annual legume (pulse) crops in Australia, referred to as "crop topping." In Western Australia, four times as many farmers with HR rigid ryegrass practice crop topping than those with no resistance (Table 1). This practice can markedly reduce weed seed production (Gill and Holmes 1997). In Australia, there has been wide adoption of herbicide techniques to reduce seed production to manage resistance in rigid ryegrass in both annual legume crops and pastures ("spray topping") (Table 1). The Australian National Glyphosate Sustainability Working Group (2005) recommends reducing the risk of glyphosate resistance by rotating glyphosate with paraquat for preplant weed control, or using a "double knock" (or "double knockdown") technique by following in sequence a preplant glyphosate application with tillage or a paraquat-based product (Weersink et al. 2005) (Table 1).

Trends discerned in the cross-resistance patterns of weed species resistant to herbicides of the same site of action may be used as a guide for strategic herbicide use. Patterns of cross-resistance, however, cannot be accurately predicted based on field histories of herbicide use. Incidence of aryloxyphenoxypropionate (APP) resistance in HR *Avena* spp. biotypes tends to be greater than that of cyclohexanedione (CHD) resistance in many countries (Beckie et al. 1999b, 1999c, 2002; Cocker et al. 2000; Mansooji et al. 1992; Seefeldt et al. 1994). Thus, as a short-term tactic to manage ACCase target-

site resistance in populations of this species, CHDs may have a higher probability of success. An apparently widespread point mutation in the ACCase gene resulting in an amino-acid change from isoleucine to leucine at position 1781 confers resistance to some APP and CHD herbicides in several grass weed species (Délye et al. 2003; Kaundun and Windass 2004). In various grass weed species, clethodim has often controlled ACCase inhibitor–HR biotypes in dicot crops (Bradley and Hagood 2001). Apparently, the point mutation(s) that confer(s) resistance to this herbicide occurs relatively infrequently.

Individuals in a population exposed to the same selection pressure can exhibit different patterns of cross-resistance, however, highlighting the probable short-term success of this approach. Wild oat patches with different cross-resistance patterns have been documented within a field (Andrews et al. 1998; Bourgeois et al. 1997a). ALS inhibitor resistance in a population of prostrate pigweed (*Amaranthus blitoides* S. Wats.) in a field in Israel is endowed by two point mutations, each conferring a different cross-resistance pattern (Sibony and Rubin 2003). Allele-specific assays can detect different point mutations (Délye et al. 2002; Kaundun and Windass 2004; Siminszky et al. 2005). Such assays are being commercialized to determine cross-resistance patterns rapidly in HR weed populations where resistance is target-site based, providing farmers with the option of applying an effective herbicide within the same growing season as weed tissue samples are collected for testing.

Herbicide resistance is often attributed to a lack of herbicide group rotation, that is, frequent or repeated use of herbicides of the same site of action. However, there is direct epidemiological evidence for the utility of herbicide group rotations in delaying the evolution of target-site resistance. Examples where herbicide group rotation has been credited in preventing or delaying resistance in weeds include triazine-HR weeds in North America (Stephenson et al. 1990), isoproturon-HR littleseed canarygrass (*Phalaris minor* Retz.) in India (Singh et al. 1999), ACCase inhibitor–HR wild oat in Canada (Légère et al. 2000) and rigid ryegrass in Australia (Gill 1995), and ALS inhibitor-HR common cocklebur (*Xanthium strumarium* L.) in the southern U.S. (Schmidt et al. 2004), wild radish (*Raphanus raphanistrum* L.) in Australia (Hashem et al. 2001a), paddy weed (*Lindernia micrantha* D.) in Japan (Itoh et al. 1999), and weeds in field crops in Europe (Hartmann et al. 2000).

Intergroup herbicide resistance can be conferred by a non-target-site mechanism, which commonly is enhanced metabolism (De Prado and Franco 2004). Metabolic resistance has been reported much more frequently in grass than broadleaf weeds (Werck-Reichhart et al. 2000). Cases of weed resistance due to metabolic detoxification are more frequent than those attributed to target-site mutation in U.K. populations of blackgrass, *Avena* spp., and Italian ryegrass (*Lolium multiflorum* Lam.) resistant to ACCase inhibitors or other herbicides; in European populations of blackgrass resistant to ACCase inhibitors, ALS inhibitors, or chlortoluron; and in European populations of grass species resistant to ALS inhibitors (Claude et al. 2004; Marshall and Moss 2004; Moss et al. 2003). Metabolism-based resistance to herbicides of different sites of action will clearly limit the effectiveness of herbicide group rotation as a tool to delay the evolution of herbicide resistance. Testing populations to determine herbicide resistance patterns is even more important where intergroup resistance is suspected and will help identify remaining herbicide options for farmers (Beckie et al. 2000).

Herbicides that are not readily metabolized in weeds are less likely to select for metabolism-based resistance. For example, the low incidence of dinitroaniline (e.g., trifluralin) resistance may be due to the paucity of detoxification mechanisms in target plants (Holt et al. 1993). Sulfometuron and imazapyr are slowly metabolized in plants and have been used to discriminate between target-site and metabolic resistance in rigid ryegrass (Boutsalis and Powles 1995; Preston and Powles 2002b). Two major enyzme systems have been implicated in herbicide resistance due to increased detoxification—cytochrome P450 monooxygenases and glutathione *S*-transferases (Table 2). These detoxification systems are expressed both constitutively and induced (upregulated) in response to herbicide safeners. Studies of the inheritance of cytochrome P450 monooxygenase-dependent resistance in weeds have shown that a single gene can endow cross-resistance to herbicides of different sites of action applied at registered rates (Letouzé and Gasquez 2001; Preston 2004). Cross-resistance can frequently occur between ACCase and ALS inhibitors, or between photosystem-II inhibitors and ACCase inhibitors (Preston 2004). However, different patterns of cross-resistance can occur in different species (Preston and Mallory-Smith 2001).

Herbicides used in sequences or rotations that are detoxified via pathways different from these two enzyme systems, or that are slowly or not metabolized (e.g., glyphosate, glufosinate, paraquat), will reduce the risk of selecting for metabolism-based, intergroup-HR weed

Table 2. Herbicides metabolized by cytochrome P450 monooxygenases (P450s) or glutathione *S*-transferases (GSTs) in herbicide-resistant weed biotypes.

Species	P450s	GSTs	Herbicide	Chemical class[a]	Reference
Rigid ryegrass (*Lolium rigidum* Gaudin)	X		Simazine	Triazine	Burnet et al. (1993a)
	X		Chlortoluron	Urea	Burnet et al. (1993b)
	X		Chlorsulfuron	SU	Christopher et al. (1994)
	X		Diclofop	APP	Preston et al. (1996)
	X		Pendimethalin	Dinitroaniline	Tardif and Powles (1999)
Italian ryegrass (*Lolium multiflorum* Lam.)	X		Chlorsulfuron	SU	Bravin et al. (2004)
Blackgrass (*Alopecurus myosuroides* Huds.)	X		Chlorotoluron	Urea	Kemp et al. (1990)
	X		Isoproturon	Urea	Kemp et al. (1990)
	X		Diclofop	APP	Menendez and De Prado (1996)
		X	Fenoxaprop-P	APP	Cummins et al. (1997)
	X		Fenoxaprop-P	APP	Letouzé and Gasquez (2001)
	X		Flupyrsulfuron	SU	Letouzé and Gasquez (2003)
	X		Isoproturon	Urea	Letouzé and Gasquez (2003)
	X		Chlorproturon	Urea	Letouzé and Gasquez (2003)
	X		Haloxyfop	APP	Letouzé and Gasquez (2003)
	X		Clodinafop	APP	Letouzé and Gasquez (2003)
Sterile oat (*Avena sterilis* L.)	X		Diclofop	APP	Maneechote et al. (1997)
Littleseed canarygrass (*Phalaris minor* Retz.)	X		Isoproturon	Urea	Singh et al. (1998)
Foxtail (*Setaria*) spp.		X	Atrazine	Triazine	De Prado et al. (1999)
Late watergrass [*Echinochloa phyllopogon* (Stapf) Koss.]	X		Bispyribac	PTB	Fischer et al. (2000)
Downy brome (*Bromus tectorum* L.)	X		Propoxycarbazone[b]	SCT	Park et al. (2004)
Large crabgrass [*Digitaria sanguinalis* (L.) Scop.]	X		Imazethapyr	IMI	Hidayat and Preston (2001)
Common chickweed [*Stellaria media* (L.) Vill.]	X		Mecoprop	Phenoxy	Coupland et al. (1990)
Velvetleaf (*Abutilon theophrasti* Medicus)		X	Atrazine	Triazine	Anderson and Gronwald (1991)
Wild mustard (*Sinapis arvensis* L.)	X		Ethametsulfuron	SU	Veldhuis et al. (2000)
Annual sowthistle (*Sonchus oleraceus* L.)		X	Simazine	Triazine	Fraga and Tasende (2003)

[a] Abbreviations: APP, aryloxyphenoxypropionate; IMI, imidazolinone; PTB, pyrimidinylthiobenzoate; SCT, sulfonylamino-carbonyltriazolinone; SU, sulfonylurea.

[b] Proposed name. Chemical name: methyl 2({[4-methyl-5-oxo-3-propoxy-4,5-dihydro-1*H*-1,2,4-triazol-1-yl]carbonyl}amino}sulfonyl)benzoate sodium salt.

biotypes. Most cases of cross-resistance across herbicide sites of action have occurred through the use of wheat-selective herbicides (Hidayat and Preston 2001). Thus, herbicides not selective in wheat, such as sethoxydim or clethodim, and nonselective herbicides used in HR crops, such as glyphosate or glufosinate, will be important tools for managing metabolic resistance in grass weed biotypes in the future.

Herbicide-Resistant Crops: A Double-Edged Sword. Adoption of HR crops is driven primarily by easier and improved weed control or higher net returns (Burnside 1992; Devine and Buth 2001). Cultivation of such crops will increasingly influence future herbicide-use patterns. Globally, resistance to nonselective herbicides (i.e., glyphosate, glufosinate) is the dominant type of transgenic crop (72%, stacked traits excluded), and cultivated area has continued to expand since 1995 (Table 3). HR soybean [*Glycine max* (L.) Merr.] comprises the largest area at 48.4 million ha or 60% of the area planted to transgenic crops. Other important transgenic-HR crops include corn (*Zea mays* L.) (10% by area), cotton (about 6%), and canola (6%). Worldwide, 56% of soybean, 19% of canola, 15% of cotton, and 6% of corn planted in 2004 were transgenic-HR cultivars.

The judicious use of HR crops can slow the selection of HR weeds by increasing herbicide rotation options, such as the substitution of high-risk herbicides with lower-risk products. Nonselective herbicides used in HR crops in North America have been a powerful tool to proactively and reactively manage HR weeds, such as those resistant to high-risk herbicides, including ACCase and ALS inhibitors (Beckie et al. 2006). As a result, the potential economic impact of these HR weeds has been diminished. However, frequent use of HR crops in cropping systems, resulting in recurrent application of herbicides of the same site of action, may select for new HR weed biotypes or augment the selection that has occurred previously. Evolved weed resistance through selection pressure in HR crops generally poses a greater risk than evolved resistance in related weed species through gene flow because frequency of interspecific hybridization and subsequent introgression is often low (Beckie et al. 2001c; Warwick et al. 1999, 2004). Notable exceptions may include gene flow from HR canola to bird's rape/field mustard (*Brassica rapa* L.) in eastern

Table 3. Transgenic[a] crops grown in 2003 and 2004, listed by country, trait, and crop (adapted from James 2003, 2004).

	2003		2004	
	ha × 10[6]	%	ha × 10[6]	%
By country:				
United States	42.8	63	47.6	59
Argentina	13.9	21	16.2	20
Canada	4.4	6	5.4	6
Brazil	3.0	4	5.0	6
China	2.8	4	3.7	5
Paraguay	0	0	1.2	2
India	0.1	<1	0.5	1
South Africa	0.4	1	0.5	1
Other	0.3	<1	0.4	<1
Total countries	18		17	
Total area	67.7		81.0	
By trait:				
Herbicide resistance (HR)	49.7	73	58.6	72
Bt (*Bacillus thuringiensis*)	12.2	18	15.6	19
HR + Bt	5.8	9	6.8	9
By crop:				
Soybean [*Glycine max* (L.) Merr.][b]	41.4	61	48.4	60
Corn (*Zea mays* L.)[c]	15.5	23	19.3	23
Cotton (*Gossypium hirsutum* L.)[d]	7.2	11	9.0	11
Canola (*Brassica napus* L.)[e]	3.6	5	4.3	6

[a] Imidazolinone-HR crops excluded.

[b] All HR.

[c] HR = 6.4 million ha (9%) in 2003 and 8.1 million ha (10%) in 2004.

[d] HR = 4.1 million ha (6%) in 2003 (data not available for 2004).

[e] All HR.

Canada (Warwick et al. 2003), HR wheat to jointed goatgrass (*Aegilops cylindrica* Host) in the western United States (Hanson et al. 2005; Seefeldt et al. 1998; Zemetra et al. 1998), and HR rice (*Oryza sativa* L.) to red rice (*O. sativa* L.) in the Americas (Gealy et al. 2003).

Potential impact of HR crops on selection for weed resistance is largely dependent on the size and intensity of the cropped area in an agricultural region and the herbicide site of action. Occurrence of glufosinate-HR weeds has not been reported. There are relatively few reports of weeds resistant to photosynthesis inhibitors at photosystem II (benzonitriles) (Heap 2005). The largest class of HR weeds worldwide are those resistant to ALS inhibitors. The use of ALS inhibitor herbicides in imidazolinone-HR crops will continue the selection for ALS inhibitor-HR broadleaf and grass weeds. Unless imidazolinone-HR crops and ALS inhibitor herbicides are used wisely, their commercial success will be limited.

Since the introduction of glyphosate-HR crops in the mid-1990s, several weed species resistant to the herbicide have been reported (Heap 2005). The majority of glyphosate-HR biotypes were not a consequence of glyphosate selection pressure in HR field crop production systems, but in orchards and vineyards, roadsides, or non-HR crops (e.g., preplant, preharvest, or postharvest).

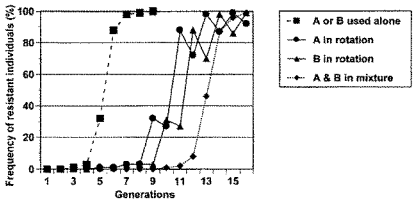


Figure 2. Predicted evolution of herbicide resistance (dominant inheritance) in an outcrossing weed species following repeated selection with herbicides A and B used alone, in a rotation, or in a mixture (adapted from Powles et al. 1997).

To date since 2000, however, evolution of three glyphosate-HR biotypes has been linked to glyphosate-HR cropping systems in the United States. In various regions of the United States, sequential in-season applications combined with near glyphosate-HR soybean monoculture (or glyphosate-HR cotton) have contributed to the evolution of glyphosate-HR horseweed across a large area in more than 10 states, glyphosate-HR common ragweed (*Ambrosia artemisiifolia* L.) in Missouri, and glyphosate-HR Palmer amaranth (*Amaranthus palmeri* S. Wats.) in Georgia (Heap 2005). Such practices create an intense selection pressure for weed resistance and jeopardize the future utility of this important herbicide. Given the importance of glyphosate in reduced-tillage cropping, monoculture glyphosate-HR crops and multiple in-crop glyphosate applications should be dissuaded. The inexpensive cost of glyphosate relative to total variable costs and its lack of soil residual activity are disincentives for a reduction in herbicide-use intensity. Nevertheless, greater implementation of IWM practices in glyphosate-HR crops, such as an intermediate (e.g., 38 cm) rather than a wide (e.g., 76 cm) row spacing in soybean (Chandler et al. 2001), can reduce weed populations and thus help reduce the real or perceived need for sequential in-crop glyphosate applications.

Herbicide Mixtures. Based on the compounded resistance frequency model, herbicide mixtures are predicted to delay resistance longer than rotations (Diggle et al. 2003; Powles et al. 1997) (Figure 2). Field experiments are being conducted to verify model predictions (H. Beckie, unpublished data). Acceptance by farmers of herbicide mixtures for resistance avoidance has been aided by cost-incentive programs from industry, formulated mixtures (e.g., phenoxy plus an ALS inhibitor), and the rapid evolution of resistance in specific cases. The herbicide combinations may be applied at lower individual

herbicide rates (Little and Tardif 2005), especially when interacting synergistically (Gressel 1990). A survey of 1,800 farmers in western Canada from 2001 to 2003 indicated that a majority of them tank-mix herbicides to delay or manage ALS inhibitor-HR broadleaf weeds (H. Beckie, unpublished data).

If mixing partners of different sites of action do not meet the criteria of similar efficacy and persistence, plus different propensity for selecting for resistance in target species, the effectiveness of mixtures for delaying target-site resistance will be reduced. For example, a mixture of an ALS inhibitor, chlorimuron, and metribuzin for ALS inhibitor resistance management of common waterhemp in the mid-western United States is not effective because chlorimuron is more persistent than metribuzin and common waterhemp has uneven and season-long emergence (Sprague et al. 1997). Imazaquin applied with pendimethalin did not delay imazaquin resistance in smooth pigweed because pendimethalin did not adequately control the species (Manley et al. 1998). Mixtures can inadvertently accelerate the evolution of multiple resistance if they fail to meet basic criteria for resistance management and are applied repeatedly (Rubin 1991). A biotype of rigid ryegrass became resistant to a mixture of amitrole and atrazine after 10 yr of widespread and repeated use (Burnet et al. 1991). To effectively delay metabolic resistance, the mixing partners must be degraded via different biochemical pathways (Wrubel and Gressel 1994). However, information on the mode of degradation of herbicides in plants is not known by farmers. Furthermore, mixtures to prevent or delay metabolic resistance in grass weeds, where this mechanism is most prevalent, may be cost-prohibitive unless graminicide partners interact synergistically and can be applied at lower rates.

Challenges to farmer adoption of mixtures for herbicide resistance management include increased cost and availability of suitable mixing partners that meet the criteria outlined above. The inherent limitation of mixtures in delaying target-site resistance is illustrated by the following example. The ALS inhibitor herbicide, thifensulfuron plus tribenuron (formulated mixture), is popular for controlling broadleaf weeds in cereal crops in the northern Great Plains. The phenoxy herbicide, MCPA, is registered as a tank mixture with this ALS inhibitor (Anonymous 2005). Eleven weed species are controlled by both mixing partners, including ball mustard [*Neslia paniculata* (L.) Desv.], kochia, redroot pigweed, Russian thistle (*Salsola iberica* Sennen & Pau), field pennycress (*Thlaspi arvense* L.), and wild mustard (*Sinapis arvensis* L.). This mixture should markedly delay ALS inhibitor target-site resistance in these species, particularly those that are highly self-pollinated, such as field pennycress. MCPA poses a low risk for selecting for resistance (Figure 1), both mixing partners have short soil residual activity, and MCPA is inexpensive. However, the rate of MCPA used in the mixture may result in reduced efficacy on some species, such as redroot pigweed and Russian thistle, compared with that of the ALS inhibitor herbicide. Moreover, common chickweed [*Stellaria media* (L.) Vill.] and common hempnettle (*Galeopsis tetrahit* L.) are only controlled by the sulfonylurea herbicide. Numerous ALS inhibitor-HR populations of these two species have been reported.

There is limited anecdotal evidence of the usefulness of mixtures in herbicide-resistance management. Mixtures with ALS inhibitors have successfully delayed ALS inhibitor resistance in weeds in rice in Japan and in field crops in Europe (Gressel 1997; Itoh et al. 1999). Farmers who included mixtures of herbicides with different sites of action coupled with various cultural practices were less likely to select ALS inhibitor–HR weed populations (Shaner et al. 1997). *Chenopodium* and *Amaranthus* spp., which often have evolved triazine resistance when triazines were used alone, rarely have been reported to evolve resistance where atrazine plus chloracetamide mixtures were used for over 20 yr in monoculture corn in North America (Wrubel and Gressel 1994). Atrazine is applied at a lower rate in this mixture, thus reducing selection pressure. Pendimethalin is an effective mixing partner (or when used in sequence) for propanil to delay or manage propanil resistance in junglerice [*Echinochloa colona* (L.) Link] in rice in Central America (Riches et al. 1997; Valverde 1996).

Effective resistance management is realized by herbicide mixtures that result in synergistic effects. Some carbamates and organophosphates competitively inhibit aryl acylamidase (EC 3.1.1.a), the enzyme responsible for catalyzing propanil metabolism in rice and propanil-HR junglerice. This inhibition can result in synergistic effects. A formulation of propanil and piperophos, a phosphoric herbicide, was first marketed in 1995 in Costa Rica and cost-effectively controls propanil-HR junglerice while achieving selectivity in rice (Valverde 1996; Valverde et al. 1999). Mixtures comprising a reduced rate of propanil and piperophos or anilofos are now widely used in Costa Rica and Columbia (Valverde et al. 2000). Similarly, mixtures of anilofos or piperophos with propanil at various rate combinations synergistically control propanil-HR barnyardgrass in rice in

Table 4. Propanil in combination with piperophos for selective control of propanil-resistant barnyardgrass in rice; additive (A) or synergistic (S) effects (adapted from Norsworthy et al. 1999a).

Propanil	Piperophos	Weed control	Rice injury
kg ai/ha		%	
0.83	0	33	0
	0.11	43 A	0
	0.33	42 A	0
	1.0	56 A	0
	3.0	63 S	1
1.65	0	53	0
	0.11	64 A	0
	0.33	57 A	1
	1.0	81 S	4
	3.0	86 S	3
3.3	0	62	0
	0.11	78 A	1
	0.33	83 A	3
	1.0	96 S	3
	3.0	93 S	4
6.6	0	81	0
	0.11	92 A	3
	0.33	94 A	5
	1.0	99 A	8
	3.0	98 A	7
LSD (0.05)		14	3

the southern United States with little or no crop injury (Daou and Talbert 1999; Norsworthy et al. 1999a, 1999b; Talbert et al. 2000) (Table 4).

Can herbicide rotations or mixtures exploit reduced fitness of herbicide-resistant weeds and negative cross-resistance? Reduced fitness of triazine-HR plants compared with HS plants, documented frequently in the 1970s, resulted in optimistic predictions that this "cost of resistance" would also be prevalent in biotypes resistant to herbicides of other sites of action (Gressel and Segel 1982). The target-site mutations conferring most cases of triazine resistance reduce photosynthetic efficiency, which is often manifested by decreased plant productivity and competitiveness (i.e., reduced fitness). Upon discontinuation of triazine herbicides, reduced fitness of HR compared with HS biotypes was predicted to reverse the evolution of resistance at a rate dependent on the fitness differential between biotypes. Unfortunately, reduced fitness of biotypes resistant to herbicides of other sites of action has generally been minimal or not detectable (Holt and Thill 1994). Lack of measurably reduced fitness in HR biotypes has been inferred from little decline in the proportion of HR:HS individuals measured in fields over time after use of the selecting herbicide was discontinued (Andrews and Morrison 1997). For noncompetitive inhibitors of target-site enzymes, such as ACCase or ALS, the various sites of mutations for resistance are not near the active site of the enzyme and thus there is little fitness loss detectable due to lower affinity for the normal substrates (Gressel 1999; Wrubel and Gressel 1994).

Negative cross resistance, that is, HR plants are more sensitive to a herbicide than HS plants, has been documented in several triazine-HR weed biotypes (Dabaan and Garbutt 1997; Gadamski et al. 2000; Jordon et al. 1999; Parks et al. 1996). Some herbicides that inhibit photosystem II bind more efficiently to the mutant triazine binding domain than to the wild (HS) type. Triazine-HR weeds frequently show negative cross resistance to other photosystem-II inhibitors, such as bentazon and pyridate; triazine-HR weeds can also exhibit negative cross resistance to herbicides that do not affect photosystem II (Gadamski et al. 2000). Explanations for this phenomenon depend on the specific herbicide, but are largely speculative. The potential combined value of negative cross-resistance and general lack of fitness of triazine-HR biotypes in managing triazine resistance in weeds worldwide has yet to be realized (Gadamski et al. 2000). Nevertheless, pyridate is now mixed with triazine herbicides and applied on millions of hectares annually, especially in Europe, to control triazine-HR biotypes and preserve the cost-effectiveness of this class of herbicides (Gressel 2002). Negative cross resistance has also been observed in non-triazine–HR biotypes. For example, an imidazolinone-HR smooth pigweed biotype was 10-fold more sensitive to cloransulam, another ALS inhibitor, compared with an HS biotype (Poston et al. 2001).

Herbicide Rates. Many herbicides are commonly applied at less-than-registered rates to reduce costs. For example, in-crop herbicides are applied at reduced rates to 28% of cropped land annually in western Canada (Leeson et al. 2004, 2006; Thomas et al. 2003). When farmers apply herbicides at below-registered rates, it is based primarily on their experience with a product's performance as affected by weed growth stage or environmental conditions. They expect good weed control, although they are aware of the increased risk of suboptimal control. However, herbicide rate reduction without a corresponding reduction in efficacy will have no effect on selection for resistance. Model simulations have suggested that it is not profitable to reduce herbicide rates to reduce selection pressure (efficacy or persistence) for resistance, unless accompanied by a compensating increase in nonherbicidal weed control (Diggle and Neve 2001). The resulting increase in the abundance of HS weed populations would reduce crop yield and quality and increase weed seed return to the seed bank (Gorddard et al. 1996; Morrison and Friesen 1996).

Beckie and Kirkland (2003) examined the implication

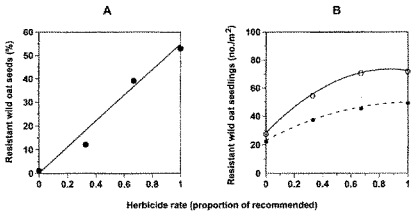


Figure 3. Implication of reduced herbicide rates on target-site resistance enrichment in wild oat: percentage of ACCase inhibitor–resistant individuals in seeds harvested after 4 yr of herbicide application at varying rates (A), and resistant seedlings recruited from the seed bank after 4 yr for the recommended (open circles) and high crop seeding rate (solid circles) treatments (B) [reproduced from Beckie and Kirkland (2003) by permission of the Weed Science Society of America].

of reduced rates of ACCase inhibitors in a 4-yr diverse crop rotation in conjunction with variable crop seeding rates on the enrichment of HR (target-site based) wild oat. As simulation models predict, reduced herbicide efficacy decreased the proportion of HR individuals in the population after 4 yr (Figure 3A). The high crop seeding rate compensated for a one-third reduction in herbicide rate by limiting total (HR plus HS) wild oat seed production and by reducing the number of HR seedlings recruited from the seed bank (Figure 3B). The study concluded that the level of resistance in the seed bank can be reduced without increasing the total seed bank population by manipulating agronomic practices to increase crop competitiveness against wild oat when ACCase inhibitor rates are reduced.

Herbicides applied at registered rates can clearly select for major gene (e.g., target-site) resistance, whereas initially, suboptimal herbicide rates may select for both major and minor gene (i.e. quantitative) resistance. Evolution of quantitative resistance relies on outcrossing among plants, resulting in incremental accumulation in their progeny of minor genes with additive or multiplicative effects (Jaseniuk et al. 1996). Therefore, such herbicide resistance is most probable and would evolve most rapidly in species such as blackgrass, rigid ryegrass, and kochia. Quantitative resistance has been documented or postulated in HR weed populations such as chlortoluron-HR blackgrass in the United Kingdom (Cavan et al. 1999; Chauvel and Gasquez 1994; Hall et al. 1994; Willis et al. 1997), diclofop-HR rigid ryegrass in Australia (Gressel 1997; Neve and Powles 2005a, 2005b; Preston and Powles 2002b), dicamba-HR kochia in North America (Belles et al. 2005; Cranston et al. 2001; Dyer et al. 2000; Westra et al. 2000), and isoproturon-HR littleseed canarygrass in India (Kulshrestha et al. 1999; Malik and Singh 1995; Singh et al. 1998, 1999). Less-than-recommended rates have been implicated or speculated as the causal factor in herbicide resistance in these biotypes. These species have a significantly or highly outcrossing mating system, except littleseed canarygrass (Malik et al. 1998).

Table 5. Incremental increase in the level of resistance (resistance factor, R/S), as measured by the dose required to kill 50% of the population (LD_{50}) or reduce biomass by 50% (GR_{50}), of rigid ryegrass biotype VLR1 after two or three cycles of selection with diclofop applied at sublethal doses (0.1 to 2 times the 1× rate of 375 g ai/ha) under greenhouse conditions (adapted from Neve and Powles 2005a).

Diclofop selection regime (proportion of 1× rate)	R/S based on LD_{50}	R/S based on GR_{50}
Nontreated control		
0.1, 0.2	7.4	6.7
0.1, 0.2, 0.5	11.8	16.3
0.1, 0.2, 1	55.8	49.3
0.1, 0.5	10.9	6.4
0.1, 0.5, 2	40.1	20.4

A population of rigid ryegrass evolved resistance to diclofop at the field-recommended rate when it was exposed to two or three cycles of sublethal rates in the greenhouse (Table 5). Similar results were found in a greenhouse study of the effect of sublethal rates of diclofop on 31 previously nontreated populations of rigid ryegrass (Neve and Powles 2005b). These results were consistent with those of a previous epidemiological study where levels of diclofop resistance in rigid ryegrass populations were positively correlated with the total amount of the herbicide applied over time and where low rates relative to those applied in other countries were typically used (Gressel 1997; Heap and Knight 1982). Maxwell and Mortimer (1994) and Gressel (1997) suggest that soil-residual herbicides may select for quantitative resistance because late-emerging weeds are exposed to lower herbicide doses that may allow accumulation of HR alleles. However, the mechanism of resistance to soil residual herbicides, such as triazines and sulfonylureas, is often target-site (i.e., major gene) mutation.

Gressel (1995) and Gardner et al. (1998) advocated a tactic of revolving herbicide doses to delay the evolution of major monogene (target site) and quantitative resistance. Routine reduced-rate application that lowers efficacy is not a good weed- or weed-resistance–management tactic (Morrison and Friesen 1996). If suboptimal rates are applied, nonherbicide methods to suppress weed seed production should be employed. Clearly, herbicides should not be repeatedly applied at suboptimal

rates to significantly or highly outcrossing target weeds, such as *Lolium* spp., blackgrass, and kochia, particularly when they occur in large populations (Gressel 2002; Jasieniuk et al. 1996).

Are there opportunities, however, to reduce rates without significantly lowering herbicide efficacy? In the past, registered rates were frequently based on the amount needed to control the least-sensitive weed, whereas other weeds on the product registration may be sensitive at much lower rates. Thus, the selection pressure on these very sensitive species can be extremely high. For example, reduced but effective ALS inhibitor herbicide rates used to control common chickweed in Europe compared with those used in North America doubled the time for resistance evolution by reducing the time those herbicides remain active in the soil (Beckie et al. 2001a; Kudsk et al. 1995). Recent trends in herbicide regulation and registration include more detailed information provided to users to adjust rates according to prevailing environment conditions and herbicide sensitivity, growth stage, or population densities of the target species; a primary regulatory objective in many countries is to promote the application of products at minimum effective doses (N. Malik, personal communication).

Site-Specific Herbicide Application. Site-specific management with the use of a global positioning system can be useful in monitoring and managing HR weed patches at early stages of development in a field over time. Unfortunately, most farmers in the northern Great Plains fail to detect small HR patches (H. Beckie, unpublished data). Comprehensive field scouting and HR weed patch management after in-crop herbicide application are usually not performed because of either a lack of awareness of the benefit of this practice or inconvenience due to large farm size. A study conducted at a 64-ha no-till site in western Canada assessed how preventing seed shed from HR wild oat affected patch expansion over a 6-yr period (Beckie et al. 2005). Area of treated patches increased by 35%, whereas nontreated patches increased by 330% (Figure 4). Patch expansion was attributed mainly to natural seed dispersal (nontreated) or seed movement by equipment at time of planting (nontreated and treated). Extensive (94 to 99%) seed shed from plants in nontreated patches before harvest or control of HR plants by alternative herbicides minimized seed movement by the combine harvester. Although both treated and nontreated patches were relatively stable over time, this study demonstrated that preventing seed production and shed in HR wild oat patches can markedly slow the rate of patch expansion. Consequently, herbicide effectiveness in a field is extended in space and time.

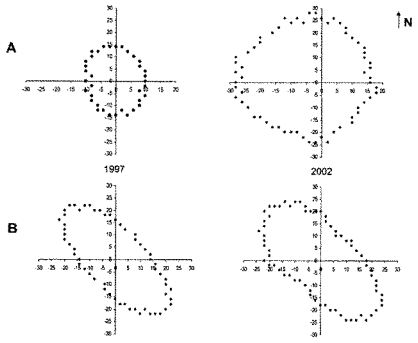


Figure 4. Patch management of herbicide-resistant wild oat in a 6-yr experiment in the northern Great Plains: a nontreated patch in 1997 and 2002 (A) vs. seed shed prevented in a patch from 1997 to 2002 (B) (*x* and *y* axis in meters, adapted from Beckie et al. 2005).

Site-specific herbicide application, utilizing weed abundance as a basis for delineating application areas in a field, would allow some reduction in the overall selection pressure. Costs of acquiring reliable weed-abundance distribution maps and herbicide application have limited its adoption by dry-land farmers growing relatively low cash-value crops. The effect of precision herbicide application on the rate of evolution of resistance would depend on the frequency of herbicide application to specific areas of a field over time and the proportion of the field treated each year. If application frequency of herbicides to specific areas of a field (e.g., lower-slope areas) is similar to conventional herbicide application, HR gene (seed, pollen) flow from these field areas to those treated less frequently may negate any potential benefits of the technology. Furthermore, if these treated areas contain the majority of the weed population present in the field, then this tactic may still result in a selection pressure similar to that of a blanket application.

Analogous to the refugia tactic in crops possessing the *Bacillus thuringiensis* trait to mitigate insect resistance, HS weed refuges has been proposed as a tactic to delay the evolution of herbicide resistance. However, leaving refugia of HS individuals to dilute the proportion of HR alleles in a population by gene flow will not be effective because the recessive control of resistance in outcrossing weed species is rare (Jasieniuk et al. 1996). Additionally, in cases of triazine resistance conferred by chloroplast

gene mutation, genetic recombination among plants does not occur (Stankiewicz et al. 2001). The only documented case of recessive inheritance of major monogene resistance in an outcrossing species was that of a picloram-HR yellow starthistle (*Centaurea solstitialis* L.) biotype found in the state of Washington (Sabba et al. 2003; Sterling et al. 2002).

INTEGRATING NONHERBICIDE TACTICS WITH HERBICIDES

Minimizing weed seed production is central to both HR and non-HR weed management programs. Cultural or mechanical practices affect weed population densities and seed production, and thus can delay the evolution of herbicide resistance by reducing the number of HR alleles in a population. Where high levels of HR alleles are believed to be present in unselected populations, such as ALS inhibitor resistance in common waterhemp and Palmer amaranth in North America (Peterson 1999) or *Lolium* spp. in Europe and Australia (Dinelli et al. 2000; Matthews and Powles 1992; Maxwell and Mortimer 1994; Preston and Powles 2002a), it is important to maintain low population densities via nonchemical methods or by using herbicides with a relatively low likelihood to select for these HR alleles. This tactic is also useful in fields where the high-risk ACCase and ALS inhibitors have been used frequently for over 20 yr. Many of these fields are likely well advanced along the herbicide-resistance evolution curve.

Cultural or mechanical practices will only halt or reverse the rate of enrichment for herbicide resistance in a weed population by eliminating selection pressure (controlling HS and HR plants equally in the absence of herbicide selection pressure) or controlling HR plants more than HS plants, respectively. Nonherbicide practices may increase the effective kill of HR plants relative to that of HS plants in situations where differences exist in the population dynamics of HR and HS biotypes. Seeds of triallate-HR wild oat are generally less dormant than those of HS populations (O'Donovan et al. 1999). Greater and more rapid emergence of HR individuals compared with HS individuals, analogous to that of ALS inhibitor-HR kochia biotypes (Dyer et al. 1993), may be potentially exploited for selective HR biotype control by tillage or nonselective herbicides before delayed planting. Similarly, triazine-HR black nightshade (*Solanum nigrum* L.) in The Netherlands emerges earlier than HS plants because of germination at lower soil temperatures (Kremer and Lotz 1998). In contrast, early planting of winter wheat in the Pacific northwest region of the United States can potentially reduce the competitive ability of HR Italian ryegrass, which emerges later than HS individuals (Radosevich et al. 1997). Tillage to bury seeds of an HR biotype of rigid ryegrass inhibited seedling recruitment compared with that of an HS biotype (Vila-Aiub et al. 2005).

The issues of economic risk, labor availability, and time management impact the adoption of some cultural or mechanical practices for HR weed management. Moreover, some practices such as stubble burning or intensive tillage are contrary to recommendations to improve soil or air quality or conserve soil, water, and energy, and thus their use is discouraged. Evolution of herbicide resistance in weed populations often has not resulted in less herbicide use or a marked increase in nonchemical control methods, except in some cases such as intergroup resistance in weeds (Powles et al. 1997; Preston and Mallory-Smith 2001) or glyphosate-HR horseweed (Steckel et al. 2005). Used singly, the effectiveness of nonherbicide practices is lower and less consistent than that of many herbicides, and may be highly dependent on environmental conditions; when used in combination, however, nonherbicide practices can manage weeds effectively (Blackshaw et al. 2004; Gill and Holmes 1997; Matthews 1994) (Table 6). Some nonherbicide tactics and practices that have proven effective in managing HR weeds are summarized below.

Cropping Systems and Practices. Crop rotations are dictated primarily by profit potential and not the management of HR weeds. Crop rotation, however, is frequently cited as one of the most influential factors in delaying or managing HR weeds (Bourgeois et al. 1997b; Carey et al. 1995; Chauvel et al. 2001; Gill and Holmes 1997; Hartmann et al. 2000; Powles et al. 1997; Ritter and Menbere 1997; Shaner et al. 1999; Singh et al. 1999; Stephenson et al. 1990). Diversity in sequences of crop types and phenologies in a rotation (i.e., dicots vs. monocots; winter- vs. spring-planted; cool vs. warm season; annual vs. perennial) may directly or indirectly reduce weed populations. Crop rotations can facilitate herbicide rotation or reduction (Beckie and Gill 2006). A field study in the northern Great Plains linked ACCase and ALS inhibitor resistance in wild oat to a lack of crop rotation diversity (Beckie et al. 2004). Inclusion of fall-planted and perennial forage crops in annual spring crop-based rotations effectively slowed the evolution of herbicide resistance in this weed species (Figure 5). A field survey documented the ability of 3- to 6-yr alfalfa (*Medicago sativa* L.) stands to reduce wild oat populations in cropping systems through crop competition and cutting

Table 6. Effect of cropping system on density of ACCase inhibitor-resistant blackgrass in the final year of an experiment in Burgundy, France (adapted from Chauvel et al. 2001).

Crop rotation[a]	Tillage[b]	Planting date[c]	Herbicide use[d]	Density
				no./m^2
WB-WW-WW	Chisel all	Early	High	9.3
	Moldboard all	Delayed	High	0.8
	Chisel all	Delayed	Low	29
SB-SP-WW	Chisel all	Early	High	1.9
	Chisel-chisel-moldboard	Delayed	High	0.3–1.4[e]
	Chisel all	Delayed	Low	10

[a] Winter barley–winter wheat–winter wheat (WB–WW–WW) vs. spring barley–spring pea–winter wheat (SB–SP–WW).

[b] Tillage regime (plowing) after crop harvest.

[c] Relative to the local area.

[d] Relative intensity of use of alternative herbicides.

[e] Split treatments consisting of postemergence nitrogen fertilization at low and normal rates, respectively.

regime of the crop for hay (Ominski et al. 1999). The survey found that wild oat population densities were reduced by 96% in cereal fields that followed alfalfa versus a cereal crop.

Traditionally, Australian agriculture was based on crop–pasture rotation systems. A 3-yr pasture phase was shown to be a low-economic-risk option (Gill and Holmes 1997; Pearce and Holmes 1976). Rigid ryegrass population density was reduced 88 to 96% in wheat following pasture grazed in the spring during the flowering and reproduction stages of the weed (Pearce and Holmes 1976). The combination of grazing and nonselective herbicides (spray topping) reduces rigid ryegrass seed production, resulting in a rapid and marked decline in weed abundance (Gill and Holmes 1997). Preference for continuous annual cropping systems and poor economic returns, however, have led to a decline in the widespread inclusion of pastures in rotations (Monjardino et al. 2004).

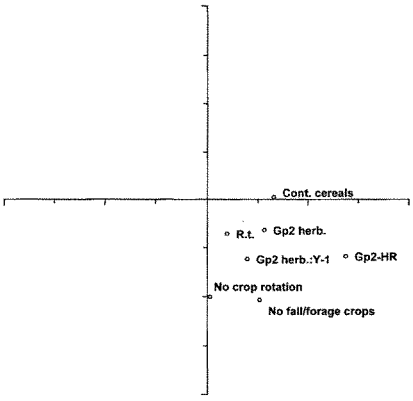


Figure 5. Significant associations between ALS inhibitor–resistant wild oat (Gp2-HR) and management practices in the northern Great Plains as determined from multiple correspondence analysis (Cont. cereals, continuous cereals; R.t., reduced tillage; Gp2 herb., ALS inhibitor used in current year; Gp2 herb.:Y-1, ALS inhibitor used 1 yr before; No crop rotation, crop rotation not used; No fall/forage crops, fall-planted or forage crops not used) (adapted from Beckie et al. 2004).

The potential value of crop rotation to delay or manage HR weeds will not be realized unless accompanied by diversification or reduction in herbicide use. Repeated use of herbicides with the same site of action will negate the weed-suppression benefits associated with crop rotation. Crop rotations had little influence on occurrence of ACCase inhibitor–HR wild oat in the northern Great Plains because farmers frequently applied these herbicides to cereal, oilseed, and annual legume crops that dominate cropping systems (Légère et al. 2000). Occurrence of resistance in wild oat was the lowest in rotations where frequency of fallow was the highest because of the reduced frequency of herbicide use. Similarly, despite diversity in crop rotations in Western Australia, repeated triazine use in different crops selected for triazine resistance in wild radish (Hashem et al. 2001b).

Inclusion of competitive crops and competitive cultivars of a crop in rotations is viewed by farmers as being important in HR weed management (Bourgeois et al. 1997b; Shaner et al. 1999). Quantitative trait loci for traits in wheat associated with weed competitiveness have been identified. These markers can be used by crop breeders to select for weed-competitive genotypes (Coleman et al. 2001). However, crop competitiveness can also be enhanced by increasing seeding rates. With the widespread appearance of HR rigid ryegrass, many Australian farmers are routinely increasing crop seeding rates by 20 to 40%, resulting in greater plant densities,

to improve competitiveness (Table 1) (Gill and Holmes 1997; Medd et al. 1987; Powles 1997). This practice is most cost effective for cereals. In the northern Great Plains, increased crop seeding rate is the most consistent cultural practice for managing weeds and maintaining crop yields (Beckie and Kirkland 2003; Blackshaw et al. 2004).

Delayed planting is often promoted for the control of some HR grass weed species in Europe, such as winter wild oat (*Avena ludoviciana* Durieu), hood canarygrass (*Phalaris paradoxa* L.), and blackgrass (Table 6, Chauvel et al. 2001; Orson 1999; Sattin et al. 2001), by depleting the seed bank before crop planting. Delayed rice planting in Central America is commonly used to reduce HR junglerice population densities (Valverde et al. 2000, 2001). In Australia, delayed crop planting has been integrated with other control tactics to manage HR rigid ryegrass (Table 1) (Gill and Holmes 1997; Powles and Matthews 1996).

Tillage Systems. Owen (2001b) reviewed the impact of tillage and mechanical practices in managing HR weed populations. The judicious use of timely tillage has been cited often as an important practice to delay or manage HR weeds (Bourgeous et al. 1997b; Chauvel et al. 2001; Orson and Livingston 1987; Peterson 1999; Stephenson et al. 1990). Tillage may substitute for herbicide use or influence seed bank dynamics. For example, plowing to bury weed seeds of blackgrass to reduce germination and emergence has been proven highly effective for management of HR populations in Europe (Moss 1997; Orson and Livingston 1987). Timely tillage can also stimulate weed germination before crop planting, such as "autumn tickle" (Table 1) (Boutsalis and Powles 1998; Gill and Holmes 1997).

Anecdotal field observations have frequently linked herbicide resistance in weeds to conservation-tillage systems, particularly no-till, which are increasingly being adopted by farmers because of cost and time efficiencies. Ratification of the Kyoto Protocol on greenhouse gas emissions will further encourage farmers to adopt reduced-tillage systems through economic incentives to increase carbon sequestration in soil. In a field study by Beckie et al. (2004), ALS inhibitor–HR wild oat was associated with such systems (Figure 5). Reduced tillage substitutes herbicide use for tillage to varying degrees. Reduced-tillage cropping can increase the abundance of specific weed species and consequently, result in greater herbicide use. However, an analysis of multiple studies found little evidence that reduced tillage increases herbicide use (Nazarko et al. 2005; Zhang et al. 2000). In the absence of tillage, weed seedlings may be derived largely from seeds shed in the previous crop and concentrated near the soil surface. Consequently, there will be little buffering against resistance evolution from old seeds, which may have greater percentage susceptibility (Moss 2002).

Limiting Herbicide-Resistance Gene Spread. Gene flow through pollen or seed movement from HR weed populations can provide a source of HR alleles in previously HS populations. Because rates of gene flow are generally higher than rates of mutation, the time required to reach a high level of herbicide resistance in such situations is greatly reduced (Jaseniuk et al. 1996). It is difficult to control the spread of herbicide resistance via pollen flow, especially when resistance is often endowed by a single, dominant or semidominant gene (Letouzé and Gasquez 1999; Richter and Powles 1993; Smeda et al. 2000). For example, pollen of ALS inhibitor–HR kochia can move more than 30 m in a cropped field (Mallory-Smith et al. 1993), and ACCase inhibitor–HR alleles in rigid ryegrass pollen can move more than 10 m in cropped or noncropped conditions (Hawthorn-Jackson et al. 2003). Seed movement is probably responsible for the majority of gene flow in weed populations (Diggle and Neve 2001). Seed movement has the potential to influence HR gene spread on a much larger scale than pollen flow.

HR weed seed spread within and among fields has been documented (Andrews et al. 1998; Hidayat et al. 2004; Li et al. 2000; Ritter and Menbere 1997; Stephenson et al. 1990; Tsuji et al. 2003). Fields within farms are more likely to have HR weeds than randomly picked fields, indicating movement of HR seed between fields via equipment (Anderson et al. 1996) or similar selection pressure among fields within a farm. Sharing of equipment among farmers has also been implicated in herbicide resistance (Debreuil et al. 1996). Weed seed spread by machinery, noncomposted manure, silage, or contaminated commercial seed stocks or feed (Ritter and Menbere 1997; Stephenson et al. 1990) is generally greater than natural seed dispersal. For example, wild oat seeds can spread more than 150 m by a combine harvester (Shirtliffe and Entz 2005). Spread of herbicide resistance among wild oat (*Avena* spp.) patches within 350 m of each other has been documented in the United Kingdom (Cavan et al. 1998). Wind dispersal of weed species having lightweight seeds, such as prickly lettuce (*Lactuca serriola* L.) (Rieger et al. 2001) and horseweed (Dauer and Mortensen 2005; VanGessel 2001), can also spread herbicide resistance rapidly. Wind can efficiently trans-

Table 7. RIM (resistance and integrated management) model scenarios: Economically optimal frequency of integrated weed management (IWM) practices when selective herbicide use is restricted over a 10-year period,[a] and resulting plant density of mature rigid ryegrass in a lupin–wheat rotation (adapted from Pannell et al. 2004).

Selective herbicide applications	Optimal frequency of IWM practices[b]				Total usage of nonselective treatments	Mature weed density[d]
	High crop seeding rates	Crop topping[c]	Seed catching	Delayed planting + glyphosate		
	No. of years over a 10-yr period				no.	no./m^2
2	10	5	10	10	35	3
4	10	5	10	6	31	6
6	10	4	10	2	26	8
8	10	2	10	1	23	6
10	6	1	10	0	17	6

[a] Usage of ACCase- or ALS-inhibiting herbicides restricted for proactive or reactive resistance management.

[b] Frequency of use of IWM practices resulting in greatest profitability over a 10-yr period for a given frequency of selective herbicide use.

[c] Lupin phase only.

[d] 10-yr mean.

port kochia and Russian thistle tumbleweeds for long distances (Mallory-Smith et al. 1993). As the incidence of herbicide resistance increases in a region, pollen and seed movement in addition to selection will increasingly influence such occurrences.

Management practices that limit the spread of HR seed can slow the occurrence of herbicide resistance. In western Canada, farmers who reported practicing weed sanitation (e.g., cleaning harvesting and tillage equipment when moving between fields, covering the grain truck box, mowing or spraying ditches or uncontrolled weed patches, applying composted versus fresh manure) were less likely to have HR wild oat than those who were less careful (Légère et al. 2000). Cleaning equipment when moving among fields, and mowing weed patches, ditches, and headlands ranked fourth and fifth, respectively, in importance among herbicide-resistance-management practices cited by farmers in western Canada (Bourgeois et al. 1997b). If the HR population covers a wide area across the field, management should focus on reducing seed return and spread by using low-risk herbicides in conjunction with cultural practices, such as cutting the crop (hay, silage, or green manure) before or soon after flowering of the HR weed species, growing competitive annual crops such as barley (*Hordeum vulgare* L.) or perennial crops, or collecting weed seeds at harvest. Weed populations can decline rapidly within one to two growing seasons for species having a relatively short-lived seed bank, such as rigid ryegrass.

Capture of weed seeds during the harvest operation is a technique used primarily by farmers dealing with herbicide resistance (Table 1). Some weed species, such as rigid ryegrass, do not shed seeds until well after maturity and therefore allow farmers the opportunity to collect seeds during harvest. In Western Australia, Gill (1996) reported a 60 to 80% removal of rigid ryegrass seeds, which reduced weed infestation in the subsequent crop by 73%. Although weed seed catching/removal at harvest is effective in managing HR weeds (Gill 1997; Gill and Holmes 1997; Matthews 1994), farmer adoption is low (Powles 1997; Shaner et al. 1999; Thill et al. 1994) (Table 1). In contrast, weeds such as wild oat may shed most seeds by cereal crop harvest in the northern Great Plains. Therefore, harvesting after extensive seed shed can reduce HR wild oat seed spread by equipment (Beckie et al. 2005).

Decision-Support Systems. Use of a decision-support system (DSS) can help farmers choose the best combination of IWM practices to delay or manage HR weeds on their farm. The most advanced DSS to date is the RIM (resistance and integrated management) model developed for IWM of single or multiple species in Australia (Monjardino et al. 2003; Pannell et al. 2004). It allows farmers to quickly assess the agronomic and economic performance of numerous combinations of management options over varying time frames (Table 7). Such a DSS, when continually maintained and updated, can be a useful tool for farmers to combat herbicide resistance in weeds.

CONCLUSIONS

Proactive or reactive management for herbicide resistance in weeds (a) must consider the relative risks of herbicides of different sites of action to select for target-site resistance and the differing propensity of herbicides to be metabolized in HR biotypes when sequencing or rotating herbicides; (b) must meet basic criteria for effective herbicide mixtures; and (c) should incorporate

agronomic practices in cropping systems that help reduce weed seed production and spread. Use of low-risk, nonselective herbicides applied preplant or in HR crops has improved HR weed management. However, frequent use of HR crops such as those resistant to imidazolinones or glyphosate may maintain conditions that lead to resistance, namely, simplified cropping systems favoring a few dominant weed species and frequent use of single site-of-action herbicides.

The extent to which farmers alter their current farming systems to manage herbicide resistance depends on the nature and magnitude of infestation of an HR biotype. In many cases, simply switching to an alternative herbicide will cost-effectively control the HR population. For serious herbicide resistance problems, for example, heavy infestations of intergroup-HR weed species, a longer-term cropping systems approach may be required. Approaches to IWM differ, depending on agroecological conditions, biology, and ecology of the weed species with evolved resistance, and agronomic and socioeconomic considerations by farmers. Although herbicides remain the dominant weed-control tool, diversification in cropping systems and practices can result in less herbicide used and thus a reduction in selection pressure for resistance. Even serious weed-resistance problems can be managed successfully if farmers are receptive to changes in their cropping systems. The increasing incidence and complexity of herbicide resistance in weeds will inevitably require farming systems with a reduced dependence on herbicides.

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October 15, 2010

The Honorable Jim Jones
Deputy Assistant Administrator
Office of Chemical Safety and Pollution Prevention
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., N.W.
Washington, D.C. 20460

Dear Mr. Jones:

In connection with the September 30, 2010 hearing of the Domestic Policy Subcommittee, entitled, "Are "Superweeds" an Outgrowth of USDA Biotech Policy? (Part II)", I hereby request that you provide answers in writing to the following questions for the hearing record.

1. Has USDA asked EPA to share its expertise on preventing pesticide resistance in the context of USDA's preparation of an environmental impact statement for Roundup Ready Alfalfa?
2. How many discussions or communications between USDA and EPA have specifically concerned 1) how USDA might mitigate or prevent the spread of Roundup resistance in weeds; and/or 2) how USDA might create a process whereby the agency would develop ways of mitigating or preventing the spread of Roundup resistance in weeds?
3. Does EPA believe that the Roundup Ready Alfalfa EIS now reflects adequately EPA's concern about pest resistance?

Ranking member Jordan submits the following additional questions:

1. Are there new technologies currently under review by USDA and EPA that would offer multiple modes of action to address weed resistance? Given the urgency expressed by the entire panel to address the issue of herbicide-resistant weeds, are there plans to expedite regulatory approval process to facilitate availability of these new technologies?

2. Is it true that development and registration of a new pesticide active ingredient takes 8 to 10 years, costs hundreds of millions of dollars, and requires more than 100 scientific studies conducted at the manufacturer's expense? After approval, does EPA continues to monitor use of the pesticide in the marketplace?
3. Had farmers experienced problems with herbicide-resistant weeds prior to the introduction of biotech crops?
4. Is there any reason to slow, delay or discourage the development and approval of new herbicide-resistant crops?
5. Will the introduction of new agricultural products such as herbicide-resistant crops benefit U.S. farmers?
6. Is the approval of such products a priority for EPA?
7. What steps is EPA taking to ensure such products are available to farmers?

The Oversight and Government Reform Committee is the principal oversight committee in the House of Representatives and has broad oversight jurisdiction as set forth in House Rule X.

We request that you provide written answers to these questions as soon as possible, but in no case later than **5:00 p.m. on October 30, 2010**.

If you have any questions regarding this request, please contact Jaron Bourke, Staff Director at (202) 225-6427.

Sincerely,

Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee

cc: Jim Jordan
Ranking Minority Member

Questions for the Record
Committee on Oversight and Government Reform
Subcommittee on Domestic Policy
Hearing on "Are 'Superweeds' an Outgrowth of USDA Biotech Policy? (Part II)"
September 30, 2010

1. **Has USDA asked EPA to share its expertise on preventing pesticide resistance in the context of USDA's preparation of an environmental impact statement for Roundup Ready Alfalfa?**

The EPA and USDA/APHIS/BRS have discussed resistance management plans for herbicide resistant crops in general. USDA also asked EPA for input on the Roundup Ready alfalfa EIS, and we provided comments on that EIS describing how resistant weeds might develop in response to widespread planting of Roundup Ready alfalfa.

2. **How many discussions or communications between USDA and EPA have specifically concerned 1) how USDA might mitigate or prevent the spread of Roundup resistance in weeds; and/or 2) how USDA might create a process whereby the agency would develop ways of mitigating or preventing the spread of Roundup resistance in weeds?**

EPA has had approximately seven discussions with USDA/APHIS/BRS concerning herbicide resistant crops and the methods that could be used to manage resistance, including Roundup resistance. Several of these discussions concerned a project with the Weed Science Society of America (WSSA) to develop a comprehensive literature review to better understand the scope of herbicide resistance in genetically-engineered and non-genetically-engineered crops. The project was undertaken because controlling resistance is extremely complex and there is limited information on the most effective methods to manage resistance in the field. It is hoped that the results of the WSSA project will help EPA and USDA develop more effective methods to promote resistance management among pesticide users.

3. **Does EPA believe that the Roundup Ready Alfalfa EIS now reflects adequately EPA's concern about pest resistance?**

Upon review of the draft EIS, EPA expressed concerns to USDA regarding the development of herbicide resistant weeds. It is our understanding that USDA will incorporate EPA's comments concerning resistance into the final EIS. EPA plans to review the final EIS to determine whether EPA's concerns are addressed.

Ranking member Jordan submits the following additional questions:

1. **Are there new technologies currently under review by USDA and EPA that would offer multiple modes of action to address weed resistance? Given the urgency expressed by the entire panel to address the issue of herbicide-resistant weeds, are there plans to expedite regulatory approval process to facilitate availabilities of these new technologies?**

EPA does not regulate directly the herbicide-tolerant plant construct and cannot speak to whether the regulatory approval process will be expedited. EPA does, however, register pesticides that are used on herbicide-tolerant plants and ensures that the necessary conditions of use are adequate to protect human health and the environment. EPA is working with USDA and professional societies, including the Weed Science Society of America (WSSA), to increase understanding and use of the best practices and strategies to manage pest resistance, including resistant weeds found in herbicide-tolerant crops. EPA is also working with the American Phytopathological Society and the Entomological Society of America to identify the best practices to manage pest resistance to fungicides and insecticides. One important component of resistance management is for pesticide users to use products that have different modes of action. To facilitate this, EPA is updating its Pesticide Registration Notice which provides guidance to pesticide registrants on resistance management labeling. This work is being coordinated with Canada and Mexico through NAFTA. Additionally, EPA believes that herbicide-tolerant plants that are resistant to more than one herbicide, allowing for rotation of herbicides with differing modes of action, may be a useful tool in a comprehensive resistance management strategy.

2. Is it true that development and registration of a new pesticide active ingredient takes 8 to 10 years, costs hundreds of millions of dollars, and requires more than 100 scientific studies conducted at the manufacturer's expense? After approval, does EPA continues to monitor use of the pesticide in the marketplace?

Developing a new pesticide product can be a lengthy process. It takes time to identify new pesticidal active ingredients, determine their potential efficacy, develop the data necessary for registration, and complete the registration process. But, completing the registration process takes just a fraction of the total time needed to develop and bring a product to market. For example, the time period allowed under the Pesticide Registration Improvement Renewal Act (PRIA 2) for EPA to render a registration decision for genetically modified plant incorporated protectant (PIP) products varies from 12 to 18 months.

As to the number of scientific studies required for the registration process, and their associated costs, these are variable because the data requirements are tiered. Applicants and registrants do not share with EPA information regarding the cost of product development, therefore, EPA cannot speak to product research and development costs Additional costs may be incurred if the studies initially submitted to the Agency are deficient and do not permit us to make the necessary findings under the statute. The number of scientific studies submitted in association with a new pesticide will fluctuate depending upon the different circumstances described above.

After registration, EPA uses federal, state and private market surveys on pesticide use to understand pesticide use in the marketplace.

3. Had farmers experienced problems with herbicide-resistant weeds prior to the introduction of biotech crops?

The first herbicide resistant weed was reported in 1957 with the use of 2,4-D on sugar cane in Hawaii. There are currently 194 herbicide resistant weed species according to the

International Survey of Herbicide Resistant Weeds. The vast majority are not related to the introduction of herbicide resistant crops.

4. Is there any reason to slow, delay or discourage the development and approval of new herbicide-resistant crops?

EPA does not currently regulate directly herbicide-tolerant plant constructs. Pursuant to its authority under the Plant Protection Act, USDA regulates genetically engineered plants to ensure that these plants are not plant pests. Therefore, we cannot speak to whether there are actual bases grounded in specific regulatory scenarios to slow, delay, or discourage the approval of any particular herbicide-tolerant crop product.

5. Will the introduction of new agricultural products such as herbicide-resistant crops benefit U.S. farmers?

As a general matter, it can be stated that the introduction of new agricultural products typically provide benefits to U.S. farmers. New agricultural products can simplify weed control by allowing the use of broad spectrum herbicides on crops that would not normally tolerate these chemistries; promote no-till farming; control difficult to manage weeds; and allow growers more control over application timing. Herbicide-tolerant crops have been used in the U.S. agricultural system for over 10 years. The use of these crops has resulted in demonstrable economic and environmental benefits. Increases in herbicide resistant weeds, however, have been a concern for many farmers.

6. Is the approval of such products a priority for EPA?

As noted above, EPA does not currently regulate directly herbicide-tolerant plant constructs. EPA registers and imposes necessary conditions on use of the herbicide intended to be used in conjunction with herbicide-tolerant crops. As we do not currently regulate directly herbicide-tolerant plant constructs, we are not in a position to make approval of such products a priority. With respect to the herbicides intended to be used in conjunction with such crops, EPA approves the registration and use conditions of such herbicides according to the schedule established by the Pesticide Registration Improvement Amendments Act (PRIA 2).

7. What steps is EPA taking to ensure such products are available to farmers?

EPA collaborates with USDA/APHIS/BRS as necessary on its regulatory approvals. Moreover, EPA is working with UDSA/APHIS/BRS on improving understanding of the evolution of herbicide resistance and steps that can be taken to manage resistance.

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October 15, 2010

The Honorable Ann Wright
Deputy Undersecretary for Marketing and Regulatory Programs
U.S. Department of Agriculture
1400 Independence Ave., SW
Washington, D.C. 20250

Dear Undersecretary Wright:

In connection with the September 30, 2010 hearing of the Domestic Policy Subcommittee, entitled, "Are "Superweeds" an Outgrowth of USDA Biotech Policy? (Part II)", I hereby request that you provide answers in writing to the following questions for the hearing record.

1. You say in your written testimony that "there must be a plant pest risk to deny a full deregulation, and herbicide resistance does not constitute a plant pest risk." That is a reference to Section 411 of the Plant Protection Act. But the very next section of the Act, Section 412, covers your authority to prevent the spread of "noxious weeds." Section 412 gives the Secretary authority to "prohibit or restrict…the movement…of any plant…if the Secretary determines that the prohibition or restriction is necessary to prevent…the dissemination of a…noxious weed within the United States." Can you point us to any provision of the Plant Protection Act that limits USDA to acting exclusively under Section 411's authority and denies USDA the ability to use the authority given to it by Section 412?
2. The Act defines noxious weeds (at 7 U.S.C. § 7702) as "any plant or plant product that can directly or indirectly injure or cause damage to crops … or other interest of agriculture… or the environment" (emphasis added). Is there any limitation in the statute's definition of "noxious weeds" that prevents its application to herbicide resistant weeds?
3. A plain reading of Section 412 in the context of the Act gives the Secretary broad authority to restrict the use of Roundup-resistant crops if sound science determines that those restrictions are necessary to prevent the spread of Roundup-resistant noxious weeds. Yet the Department has not used this authority to mitigate or prevent the

spread of existing or the development of new species of herbicide-resistant weeds. Why not? Please provide all documents discussing what the scope of the Secretary's exercise of authority under Sections 411 and 412 should be, including any legal memoranda prepared since the time of the Act's enactment.

4. You say in your testimony that "industry came to us and asked us to look at partial deregulation as one way to allow the planting of a GE crop." Will you provide the Subcommittee with copies of all such petitions for partial deregulation, as well as any related documentation or materials provided by the industry?
5. You have stated in court that any partial deregulation would be subject to analysis under the National Environmental Policy Act (NEPA) and would not, therefore, qualify as a categorical exclusion from those analytical requirements. *See* Fourth Declaration of Cindy Smith, Center for Food Safety v. Vilsack, No. 3:08-cv-00484-JSW (N.D. Cal., July 15, 2010). In view of recent litigation experience in which the Department has been rebuked by separate federal courts for failing to comply with NEPA requirements, will you explain in detail what the standard(s) for a Finding of No Significant Impact would be in the case of this partial deregulation?

Ranking member Jordan submits the following additional questions:

1. Will the introduction of new agricultural products such as herbicide-resistant crops benefit U.S. farmers?
2. Is the approval of such products a priority for USDA?
3. What steps is USDA taking to ensure such products are available to farmers?

The Oversight and Government Reform Committee is the principal oversight committee in the House of Representatives and has broad oversight jurisdiction as set forth in House Rule X.

We request that you provide written answers to these questions as soon as possible, but in no case later than **5:00 p.m. on October 30, 2010.**

If you have any questions regarding this request, please contact Jaron Bourke, Staff Director at (202) 225-6427.

Sincerely,

Dennis J. Kucinich
Chairman
Domestic Policy Subcommittee

cc: Jim Jordan
Ranking Minority Member

Questions for the Record—U.S. Department of Agriculture Response
Subcommittee on Domestic Policy Hearing
"Are Superweeds an Outgrowth of USDA Biotech Policy?"
September 30, 2010

Chairman Kucinich

1. You say in your written testimony that "there must be a plant pest risk to deny a full deregulation, and herbicide resistance does not constitute a plant pest risk." That is a reference to Section 411 of the Plant Protection Act. But the very next section of the Act, Section 412, covers your authority to prevent the spread of "noxious weeds." Section 412 gives the Secretary authority to "prohibit or restrict...the movement...of any plant...if the Secretary determines that the prohibition or restriction is necessary to prevent...the dissemination of a...noxious weed within the United States." Can you point us to any provision of the Plant Protection Act that limits USDA to acting exclusively under Section 411's authority and denies USDA the ability to use the authority given to it by Section 412?

Response:

There is no provision of the Plant Protection Act (PPA) that limits the U.S. Department of Agriculture (USDA) to only using its authorities under Section 411 of the Act, and not Section 412. In fact, USDA's Animal and Plant Health Inspection Service (APHIS) uses authorities under both sections of the PPA and currently plays a significant role in protecting American agriculture from both plant pests and noxious weeds.

To clarify, Section 412 of the PPA refers to noxious weeds, and the APHIS Plant Protection and Quarantine program has always defined a noxious weed as being either invasive or spreading at an uncontrolled rate, and also as harmful in some way to agriculture or the environment. The fact that a genetically engineered (GE) plant has a resistance to an herbicide does not make that plant any more invasive, destructive, or harmful than its non-GE form. Section 412 is only relevant to the discussion of herbicide resistance if the plant itself is a noxious weed before it is genetically altered or becomes a noxious weed with herbicide resistance after it is genetically altered.

The preamble to a recent proposed rule ("Importation, Interstate Movement, and Release Into the Environment of Certain Genetically Engineered Organisms; Proposed Rule," 73 Federal Register 197 (9 October 2008), pp 60007-60048.), discusses the standard APHIS uses for 'noxious' weeds:

> "The distinction between a weed and a noxious weed warrants emphasis. "Weeds," in the broadest sense of the word, could include any plant growing where and/or when it is unwanted; even plants that are desirable in some settings may be considered weeds in others. In a narrower sense, weeds are invasive, often non-native, plants which impact natural and managed ecosystems, often with significant negative consequences due to lost yields, changes in management practices, altered herbicide use, etc. Only a fraction of these problematic weeds are considered to be so invasive, so harmful, and so difficult to

control that Federal regulatory intervention to prevent their introduction or dissemination is justified, and these are the focus of the regulatory controls placed on them by APHIS. However, any weed, and virtually any plant or plant product, can be evaluated by APHIS to determine whether its characteristics and potential impacts warrant its listing as a noxious weed."

2. The Act defines noxious weeds (at 7 U.S.C. § 7702) as "any plant or plant product that can directly or indirectly injure or cause damage to crops...or other interest of agriculture...or the environment" (emphasis added). Is there any limitation in the statute's definition of "noxious weeds" that prevents its application to herbicide resistant weeds?

Response:

There is no provision in the Act that limits that statute's definition of "noxious weeds" to prevent the definition from applying to herbicide resistant weeds. I would like to clarify that APHIS does in fact consider resistance to herbicides as one of a number of factors when the Agency determines whether a plant should be considered a Federally-listed noxious weed. The primary consideration is stated in Section 412 of the PPA which refers to noxious weeds as either being invasive or spreading at an uncontrolled rate. Further, they must be harmful to agriculture or the environment. However, no plant has been determined to be a noxious weed solely because of resistance to a single herbicide.

3. A plain reading of Section 412 in the context of the Act gives the Secretary broad authority to restrict the use of Roundup-resistant crops if sound science determines that those restrictions are necessary to prevent the spread of Roundup-resistant noxious weeds. Yet the Department has not used this authority to mitigate or prevent the spread of existing or the development of new species of herbicide-resistant weeds. Why not? Please provide all documents discussing what the scope of the Secretary's exercise of authority under Sections 411 and 412 should be, including any legal memoranda prepared since the time of the Act's enactment.

Response:

The evolution of pests to become resistance to herbicides, insecticides, and other pesticides has been an issue for farmers for decades, and is not solely caused by the use of GE herbicide tolerant crops. As exemplified by the Australian experience, it is frequently the repeated use of a single herbicide mode of action that leads to the appearance of herbicide resistant weeds. The Act does not provide authority to the Secretary of Agriculture to regulate the use of herbicides.

To halt the spread of herbicide resistant weeds, and to prevent further development of more herbicide resistant weeds, a more fundamental, scientific approach is needed to determine how herbicides result in the appearance and spread of herbicide resistant plants and how to effectively use herbicides to minimize the risk of herbicide resistant weeds. The U.S. Environmental Protection Agency (EPA), which has the authority to regulate pesticides—including herbicides—has used its pesticide registration authority to mitigate the development of insect resistance to insecticide produced by genetically engineered crops. EPA achieves this by regulating the amount of insecticide present in the environment and by imposing resistance

management plans on plant incorporated protectants that make pesticidal claims. The regulation of the insecticide and use of refuges was based on scientific research on how insect resistance develops in targeted pests, and the best strategies available, in terms of deployment of insecticides, that will minimize the development of resistance in these insects.

USDA will continue to actively support research and extension as we work to determine how plants evolve resistance to herbicides, and what mitigation measures will minimize or halt the herbicide resistance in plants. Strong science is needed to support regulation, and the USDA is committed to providing resources and expertise to help those farmers that use herbicides in their farming practices.

We are providing to you all of the documents you requested with the exception of documents that would fall under the attorney/client privilege. We would be happy to discuss access to these documents with you; however, we are unable to provide you with copies of these documents. The requested documents are included in Appendix A. They include:

Syngenta Seeds, Inc.; Availability of Petition and Environmental Assessment for Determination of Nonregulated Status for Corn Genetically Engineered To Produce an Enzyme That Facilitates Ethanol Production, 74 Federal Register 106, (4 June 2009), pp 26832-26835.

Issue Paper 2: Incorporation of the Plant Protection Act Noxious Weed Provisions, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Biotechnology Regulatory Services, April 28, 2009. *Note: Provided during public meetings on revisions to APHIS' biotechnology regulations

Importation, Interstate Movement, and Release Into the Environment of Certain Genetically Engineered Organisms; Proposed Rule. 73 Federal Register 197, October 9, 2008, pp 60008-60048.

Plant Pests, Introduction of Genetically Engineered Organisms or Products, Final Rule, Federal Register, 52 Federal Register 115, June 16, 1987, pp 22892-22915.

4. You say in your testimony that "industry came to us and asked us to look at partial deregulation as one way to allow the planting of a GE crop." Will you provide the Subcommittee with copies of all such petitions for partial deregulation, as well as any related documentation or materials provided by the industry?

Response:

Yes. The requested documents are included in Appendix B. They include:

Forest Genetics International Letter to USDA Requesting Partial Deregulation of Roundup Ready Alfalfa Events J101/J163, August 6, 2010.

Environmental report, Partial Deregulation Measures for Cultivation of Roundup Ready® Alfalfa Events J101/J163, Forest Genetics International, August 5, 2010

Monsanto and KWS Letter to USDA Requesting Partial Deregulation of Roundup Ready Sugarbeet Event H7-1, July 29, 2010.

Environmental Report, Interim Measures for Cultivation of Roundup Ready Sugar Beet Event H7-1, Monsanto, July 30, 2010.

5. You have stated in court that any partial deregulation would be subject to analysis under the National Environmental Policy Act (NEPA) and would not, therefore, qualify as a categorical exclusion from those analytical requirements. *See* Fourth Declaration of Cindy Smith, Center for Food Safety v. Vilsack, No.3 :08-cv-00484-JSW (N.D. Cal., July 15,2010). In view of recent litigation experience in which the Department has been rebuked by separate federal courts for failing to comply with NEPA requirements, will you explain in detail what the standard(s) for a Finding of No Significant Impact would be in the case of this partial deregulation?

Response:

USDA is committed to performing thorough environmental reviews and seeking the views of the public on issues before the Department, including the regulation of GE organisms. In considering a request for a partial deregulation, APHIS would follow Agency and Council on Environmental Quality (CEQ) NEPA implementing procedures to indentify the appropriate level of NEPA analysis and documentation required, prior to taking any regulatory action. APHIS would carefully consider the possible environmental impacts of each regulatory action to ensure the appropriate level of science-based analysis required for a decision is adequate and sufficient.

APHIS will conduct an analysis on each of the issues regarding a partial deregulation, and then make a determination based on the context and intensity factors from the CEQ NEPA regulations that define how an issue may "significantly" impact the human environment, found in 40 CFR § 1508.27. This includes analyzing the significance of an action in several contexts and considering both short- and long-term effects, the degree to which the proposed action affects public health or safety, and the degree to which an action may impact endangered or threatened species, among other considerations listed under the regulations.

Ranking member Jordan

1. Will the introduction of new agricultural products such as herbicide-resistant crops benefit U.S. farmers?

Response:

Yes. The use of herbicide-resistant crops has had a significant, positive impact on the agricultural community. Benefits include:

- Increased profitability and efficiency for U.S. farmers—farmers can produce higher yields on less land;
- Use of safer herbicides;
- Decreased soil erosion due to increased no-till farming.

As the world's population increases, the demand for food is growing and the land available to farm is shrinking. To ensure the United States can meet these demands and yet protect and conserve our valuable farmland, USDA is pursuing policies that promote the coexistence of biotechnology-derived, conventional, and organic methods. Biotechnology is poised to be a critical tool in addressing important global issues, including food security, sustainability, and climate change. At USDA, we advocate the safe and appropriate use of this technology to help meet the agricultural challenges and consumer needs of the 21st century.

2. Is the approval of such products a priority for USDA?

Response:

Regulating the products of biotechnology is a critical role for USDA. We are committed to a strong, science-based biotechnology regulatory program because we view it as essential to the development of a sustainable agricultural system.

I can assure you that we take the biotechnology regulatory process very seriously, and that we strive for thorough and complete reviews, which can take a significant amount of time. While we have been challenged in recent years to respond to an increasing number of petitions for deregulation, we are constantly looking for ways to improve the process. For example, we have undertaken a reorganization of our biotechnology staff, and have hired additional scientists to improve performance and efficiency. We have also awarded contracts to assist with the preparation of technical documents, and to help us evaluate the many thousands of public comments received through the NEPA process. To further strengthen our program, USDA requested an increase of nearly $5.8 million in FY 2011 for our biotechnology program. If enacted, we would hire additional staff and improve the program's responsiveness without sacrificing its thoroughness.

3. What steps is USDA taking to ensure such products are available to farmers?

Response:

From a regulatory standpoint, our goal is to have a rigorous, science-based program in place to ensure that GE products, including herbicide resistant crops, are thoroughly vetted through our process, examined under NEPA, and determined safe before use by U.S. producers. We believe that our system achieves that goal, and has enabled producers to have access to innovative technologies that contribute to our larger agricultural economy, food security, and sustainability.

It is important to point out that we've made thousands of regulatory decisions without legal challenge, and none of our plant pest determinations have been overturned in court—though we do remain concerned about the court rulings on our NEPA documentation process. However, we continue to learn from those rulings and improve our processes, leading to higher quality environmental reports and reviews.

Appendix A. Documentation Responsive to Question 3—All documents discussing what the scope of the Secretary's exercise of authority under Sections 411 and 412 should be, including any legal memoranda prepared since the time of the Act's enactment.

Syngenta Seeds, Inc.; Availability of Petition and Environmental Assessment for Determination of Nonregulated Status for Corn Genetically Engineered To Produce an Enzyme That Facilitates Ethanol Production, 74 Federal Register 106, (4 June 2009), pp 26832-26835.

Issue Paper 2: Incorporation of the Plant Protection Act Noxious Weed Provisions, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Biotechnology Regulatory Services, April 28, 2009. ***Note: Provided during public meetings on revisions to APHIS' biotechnology regulations**

Importation, Interstate Movement, and Release Into the Environment of Certain Genetically Engineered Organisms; Proposed Rule. 73 Federal Register 197, October 9, 2008, pp 60008-60048.

Plant Pests, Introduction of Genetically Engineered Organisms or Products, Final Rule, Federal Register, 52 Federal Register 115, June 16, 1987, pp 22892-22915.

Appendix B. Documentation Responsive to Question 4—Copies of all such petitions for partial deregulation, as well as any related documentation or materials provided by the industry.

Forest Genetics International Letter to USDA Requesting Partial Deregulation of Roundup Ready Alfalfa Events J101/J163, August 6, 2010.

Environmental report, Partial Deregulation Measures for Cultivation of Roundup Ready® Alfalfa Events J101/J163, Forest Genetics International, August 5, 2010

Monsanto and KWS Letter to USDA Requesting Partial Deregulation of Roundup Ready Sugarbeet Event H7-1, July 29, 2010.

Environmental Report, Interim Measures for Cultivation of Roundup Ready Sugar Beet Event H7-1, Monsanto, July 30, 2010.

April 28, 2009

Issue Paper 2: Incorporation of the Plant Protection Act Noxious Weed Provisions

I. Objective of the Proposal

The goal of incorporating the noxious weed authority of the Plant Protection Act of 2000 (PPA) into the proposed revisions to the 340 regulations is to recognize and utilize both the plant pest and the noxious weed authorities provided by the Statute. The PPA grants the Secretary of Agriculture authority to develop regulations in order to detect, control, eradicate, suppress, prevent, or retard the spread of plant pests or noxious weeds. The PPA combines the authorities of several previous related acts, including the Plant Quarantine Act of 1912 (PQA), the Federal Plant Pest Act of 1957 (FPPA), and the Noxious Weed Act of 1974 (NWA).

APHIS' current Part 340 biotechnology regulations were first promulgated in 1987 using the FPPA and PQA, which provided USDA authority to regulate the importation and interstate movement of articles that are likely to result in the introduction or dissemination of *plant pests*. APHIS is proposing to revise the Part 340 regulations to also include its PPA noxious weed authority to regulate certain GE organisms. The proposal seeks to:

- Prevent potential gaps in APHIS' Part 340 regulatory oversight, namely for GE organisms which are unlikely to pose a plant pest risk but could pose a noxious weed risk.

- Have the regulatory authority to consider a broader range of potential harm from GE plants i.e., not just their potential for being a plant pest, but also their potential to be a noxious weed.

- Improve clarity of risk assessments, by evaluating GE plants that could be considered potential noxious weeds, in addition to evaluating their potential to be plant pests.

- Be able to regulate non-living material derived from a GE plant, if APHIS concludes that such material is likely to pose a noxious weed risk (e.g., create a noxious weed harm as enumerated in the PPA by injuring the interests of agriculture, the environment, or public health).

II. Description of Significant Comments Received to date.

Commenters focused on both the issue of incorporating the noxious weed authority into the scope of the rule as well as the issue of exactly *how* the noxious weed authority would be utilized or applied.

Many commenters focused on the very broad range of significantly harmful impacts encompassed in the noxious weed definition in the PPA. In general, industry and trade groups raised concerns that APHIS should narrowly limit its interpretation of the noxious weed definition, so that it was clear, for example, that economic or aesthetic impacts alone in the

absence of any significant physical damage did not make any plant a noxious weed. On the other hand, several public interest groups and numerous individuals wanted APHIS to interpret the definition as inclusively as possible, especially with regard to impacts on the environment, public health, and marketing or product quality impacts such as indirect impacts on organic agriculture.

Some commenters felt that the proposed rule "set the bar too low" for GE plants. If the impacts of GE plants are compared against impacts of "real" noxious weeds, as proposed, then few GE plants could ever rise to that level of harm and most GE plants might be quickly evaluated by APHIS to not be under its PPA jurisdiction and thus not subject to the Part 340 regulations. That is, only those plants that are noxious weeds (or are likely to be noxious weeds) to begin with would actually be within the scope of the Part 340 regulations.

III. APHIS Current Thinking

APHIS considers that it is preferable to revise its regulations to incorporate the noxious weed authority of the PPA. Doing so would allow regulatory oversight of GE organisms that do not fall within the jurisdiction of the current regulation's plant pest authority. APHIS also considers that the proposed revisions could also improve the clarity and transparency of APHIS' biotech risk assessments and enable APHIS to consider a broader range of factors (e.g., interests of agriculture, public health, the environment) that could potentially be injured by the GE plant if it were determined to be a noxious weed. The specifics of *how* APHIS will evaluate the noxious weed risk of GE plants may require some additional development and clarification. APHIS must consistently apply its PPA noxious weed authority and thus its noxious weed assessment of GE plants under the proposed regulations must be similar to and consistent with the way that APHIS has in the past and continues to evaluate the noxious weed risk of non-GE plants. It is not justifiable either from a regulatory or a scientific perspective to hold GE plants to a different standard than non-GE plants for risks regulated under the same statutory authority by the very same agency. However, APHIS will need to develop clear criteria and decision-making standards in order to better inform the public of how it intends to apply its PPA noxious weed authority to GE plants. Those criteria and standards will likely need to be incorporated into the regulation.

IV. Issues for Further Discussion

Comments related to incorporation of the PPA noxious weed authority into the proposed regulations raised a number of issues that APHIS will have to carefully consider:

- How can APHIS apply its PPA noxious weed authority to GE plants in a way that is consistent with and similar to its past and current noxious weed regulation of non-GE plants?

- What criteria or standards for evaluating GE plants as noxious weeds could APHIS develop that are consistent with the PPA definition of noxious weeds and APHIS application of its noxious weed authority to non-GE plants?

- How can APHIS develop noxious weed criteria applicable to GE plants and relate those criteria to the various impacts included in the PPA noxious weed definition—such as impacts on "other interests of agriculture" and "public health"— that are consistent with its past and current non-GE noxious weed assessments?



Federal Register

Thursday,
October 9, 2008

Part IV

Department of Agriculture

Animal and Plant Health Inspection Service

7 CFR Part 340

Importation, Interstate Movement, and Release Into the Environment of Certain Genetically Engineered Organisms; Proposed Rule

DEPARTMENT OF AGRICULTURE

Animal and Plant Health Inspection Service

7 CFR Part 340

[Docket No. APHIS–2008–0023]

RIN 0579–AC31

Importation, Interstate Movement, and Release Into the Environment of Certain Genetically Engineered Organisms

AGENCY: Animal and Plant Health Inspection Service, USDA.

ACTION: Proposed rule; notice of public forums.

SUMMARY: We propose to revise our regulations regarding the importation, interstate movement, and environmental release of certain genetically engineered organisms in order to bring the regulations into alignment with provisions of the Plant Protection Act. The revisions would also update the regulations in response to advances in genetic science and technology and our accumulated experience in implementing the current regulations. This is the first comprehensive review and revision of the regulations since they were established in 1987. This rule would affect persons involved in the importation, interstate movement, or release into the environment of genetically engineered plants and certain other genetically engineered organisms.

DATES: We will consider all comments that we receive on or before November 24, 2008. We will also consider comments made at public forums to be held in Davis, CA; Kansas City, MO; and Riverdale, MD.

ADDRESSES: You may submit comments by any of the following methods:

- *Federal eRulemaking Portal:* Go to *http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d=APHIS-2008-0023* to submit or view comments and to view supporting and related materials available electronically.
- *Postal Mail/Commercial Delivery:* Please send two copies of your comment to Docket No. APHIS–2008–0023, Regulatory Analysis and Development, PPD, APHIS, Station 3A–03.8, 4700 River Road Unit 118, Riverdale, MD 20737–1238. Please state that your comment refers to Docket No. APHIS–2008–0023.
- *Public Forums.* Written and oral comment will be accepted at three public forums held during the comment period. See *Public Forums* below.

Reading Room: You may read any comments that we receive on this docket in our reading room. The reading room is located in room 1141 of the USDA South Building, 14th Street and Independence Avenue, SW., Washington, DC. Normal reading room hours are 8 a.m. to 4:30 p.m., Monday through Friday, except holidays. To be sure someone is there to help you, please call (202) 690–2817 before coming.

Other Information: Additional information about APHIS and its programs is available on the Internet at *http://www.aphis.usda.gov.*

FOR FURTHER INFORMATION CONTACT: Biotechnology Regulatory Services, APHIS, 4700 River Road Unit 147, Riverdale, MD 20737–1236; (301) 734–5710.

For information about the public forums, contact: Dr. T. Clint Nesbitt, BRS, APHIS, 4700 River Road Unit 147, Riverdale, MD 20737–1238; (301) 734–5673.

SUPPLEMENTARY INFORMATION:

Public Forums

In order to provide additional opportunities for the public to comment on the proposed rule, APHIS will hold public forums in three locations: Davis, CA; Kansas City, MO; and Riverdale, MD (see *Meeting Locations* below). These informal forums are designed to engage interested individuals from the public and elicit comments related to the proposed rule. The format will consist of informational posters and comment stations. Attendees will be able walk through the forum during the open hours and interact with other attendees and APHIS personnel. Short welcoming remarks will be given by APHIS personnel at 4:30 p.m. and again at 6 p.m. (local time), but there is no set schedule for each poster station, so the public may come and go at any time during the forum period. Participants will have the opportunity, if desired, to record brief oral comments with a court reporter or to submit comments in writing, following directions provided at the comment stations. A transcript of the oral comments and a copy of any written comments submitted at the public forums will be placed in the rulemaking record and will be available for public inspection.

The purpose of these public forums is to allow the public a venue in which to interact with APHIS representatives and to allow APHIS to solicit further information from the public. Comments received at these public forums will be added to this Docket.

Dates: The public forums will be held in Davis, CA, on October 28, 2008; in Kansas City, MO, on October 30, 2008; and Riverdale, MD, on November 13, 2008. Each public forum will be held from 4 p.m. to 7 p.m., local time.

Meeting Locations: The public forums will be held at the following locations:

USDA Riverside, Oklahoma City Memorial Conference Rooms B, C, and D, 4700 River Road, Riverdale, MD, 20737. For directions or facilities information, call (301) 734–8010.

Walter A. Buehler Alumni & Visitors Center, Alpha Gamma Rho Hall, University of California, Davis, CA, 95616. For directions or facilities information, call (530) 754–9195 or visit *http://www.alumnicenter.ucdavis.edu/.*

Hilton Kansas City Airport, Shawnee Room A, 8801 NW 112th Street, Kansas City, MO, 64153. For directions or facilities information, call (816) 891–8900 or visit *http://www.hiltonkci.com/.*

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I. Introduction

The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) regulates the safe introduction (environmental release, interstate movement, and importation) of certain genetically engineered (GE) organisms under its regulations in 7 CFR part 340. The regulations govern the introduction of GE organisms that might be plant pests. APHIS has amended the regulations several times in an effort to respond to the need for streamlined procedures and has established clear procedures to remove GE organisms that do not pose a plant pest risk from obligations under the regulation.

The APHIS regulations have been used most frequently for permits and notifications for importation, interstate movement, or environmental releases of GE plants, although a smaller number of permits have been issued for GE microorganisms and insects. To date, APHIS has authorized more than 13,000 environmental releases of GE plants, most of which have been part of the development of improved crop varieties for agriculture. These controlled environmental releases are sometimes referred to as field tests or field trials, in recognition of their relationship to field tests done in the traditional development of plant varieties, and in this document the terms field test or field trial should be understood to mean environmental release. In addition to permits and notifications, APHIS has completed reviews in response to petitions requesting nonregulated status under these regulations. To date, APHIS has granted 74 determinations of nonregulated status, and all of these have been for GE plants (more information about these is posted at *http://www.aphis.usda.gov/brs/not_reg.html*). Many of these plants have since been used to develop plant varieties that have become part of the options that growers have for agricultural production in the United States and other countries. The APHIS determinations of nonregulated status have been for the GE plant(s) and their progeny. The GE plant with nonregulated status can be used subsequently in plant breeding programs or in agriculture just like other plant lines. A GE plant that has received nonregulated status can be bred with another GE plant with nonregulated status, and the resulting progeny which could contain multiple GE traits still retains nonregulated status.

The bulk of APHIS-authorized introductions have been crop plants bearing genes which confer resistance to certain insects or tolerance to certain herbicides. Although the current program has been effective in ensuring the safe environmental release, interstate movement, and importation of certain genetically engineered organisms, technological advances have led to new uses and questions about how the current regulations and APHIS authorities will be used to maintain appropriate oversight. Advances in technology have created possibilities for new and different traits, such as those that would produce a compound for pharmaceutical or industrial use. In addition, researchers have been producing organisms that may not fall under the scope of our current regulations and are also beginning to focus more on perennial plants, such as grasses or trees, which may be capable of establishing and persisting outside the site of introduction.

APHIS is proposing to revise its regulations in order to respond to emerging trends in biotechnology, to address the current and future needs of the agency, to continue to ensure a high level of environmental protection, to improve regulatory processes so that they are more transparent to stakeholders and the public, to more efficiently use agency resources and to eliminate unnecessary regulatory burdens.

Given the diversity of U.S. agriculture, the USDA Advisory Committee on Biotechnology and 21st Century Agriculture recently in its March 2008 consensus report encouraged the continuing support of coexistence among various agricultural production systems in U.S. agriculture. APHIS concludes that the changes it is proposing will continue to support coexistence in U.S. agriculture.

In addition, APHIS is proposing changes to the regulations to reflect provisions of the 2008 Farm Bill recently enacted. Section 10204 of Title X of the Food, Conservation, and Energy Act of 2008 (Farm Bill) requires the Secretary of Agriculture to take action on each issue identified in the document entitled "Lessons Learned and Revisions under Consideration for APHIS' Biotechnology Framework," and where appropriate, promulgate regulations. APHIS is proposing certain regulatory changes concerning permit application information requirements, permit conditions, records, and reports that address many of the considerations outlined in Section 10204.

APHIS is also aligning this proposed rule with recommendations arising from the 2005 audit of the USDA Office of Inspector General entitled "Controls Over Issuance of Genetically Engineered Release Permits."

II. Background

A. APHIS Role in Federal Regulation of Genetically Engineered Organisms

Under the Coordinated Federal Framework for Regulation of Biotechnology,[1] USDA works with the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA) to ensure that the development and testing of biotechnology products occur in a manner that is safe for plant and animal health, human health, and the environment. USDA and EPA are the agencies responsible for protecting U.S. agriculture and the environment. EPA is responsible for the human health, animal health, and environmental safety issues raised by any pesticidal substance produced in genetically engineered (GE) organisms. FDA has authority over the safety of the whole food product other than the pesticidal components regulated by EPA.

B. Current Regulations in 7 CFR Part 340

APHIS administers regulations in 7 CFR part 340, "Introduction of Organisms and Products Altered or Produced Through Genetic Engineering Which are Plant Pests or Which There is Reason to Believe are Plant Pests" (referred to below as the regulations). The current regulations govern the introduction (importation, interstate movement, or release into the environment) of certain GE organisms termed "regulated articles." Regulated articles are essentially GE organisms which might pose a risk as a plant pest.

APHIS first promulgated these regulations in 1987 under the authority of the Federal Plant Pest Act of 1957 (FPPA) and the Plant Quarantine Act of 1912 (PQA), two acts that were subsumed into the Plant Protection Act (PPA, 7 U.S.C. 7701 *et seq.*) in 2000, along with other provisions.

Under the current regulations, a GE organism is a regulated article if it is a plant pest or if the Administrator has reason to believe it is a plant pest; more specifically:

[1] The Coordinated Framework is described in a notice published in the **Federal Register** on June 26, 1986 (51 FR 23302). The notice may be viewed at *http://www.aphis.usda.gov/brs/fedregister/coordinated_framework.pdf.*

"if the donor organism, recipient organism, or vector or vector agent belongs to any genera or taxa designated in § 340.2 and meets the definition of plant pest, or is an unclassified organism and/or an organism whose classification is unknown, or any product which contains such an organism, or any other organism or product altered or produced through genetic engineering which the Administrator determines is a plant pest or has reason to believe is a plant pest." (Definition of *regulated article*, § 340.1)

In other words, APHIS regulates the introduction (importation, interstate movement, and environmental release) of GE organisms if (1) any of the recipient, genetic donor, or vector organisms are plant pests or of unknown classification or (2) the Administrator has determined or has reason to believe the GE organism is a plant pest. As constructed the regulations apply to GE microorganisms, insects, and other traditional types of plant pests and to any GE plants if plant pest organisms (bacterial and viral plant pathogens) are the donor organisms and vector agents used in the creation of these GE plants.

Taxa containing "known plant pests" are those listed in current § 340.2. Current regulations also include a petition procedure (§ 340.5) which allows petitioners to ask APHIS to add or subtract taxa from the list in § 340.2. That list has not been amended since it was established in 1987.

As defined under the current regulations and the PPA, most plants are not plant pests, with the exception of a few parasitic plant species, such as striga, witchweed, and dodder.

The primary procedure for regulation under the PPA is the issuance of a permit, which is an authorization by the Secretary to move plants, plant products, biological control organisms, plant pests, noxious weeds, or articles under conditions prescribed by the Secretary. The PPA also authorizes the Secretary to determine which classes of the above articles must have a permit to be moved. Conditions associated with those permits can be tailored to achieve the appropriate level of regulatory control to make it unlikely that actions under the permit would result in the introduction or dissemination of a plant pest or noxious weed.

APHIS currently uses a permit and notification system to authorize importation, interstate movement and release into the environment (currently referred to as "introductions") of certain GE organisms. Under the current regulations, all regulated articles are eligible for the permitting procedure, but only certain plants are eligible for the notification procedure. Currently, most regulated GE plants are introduced under notification, which is a streamlined procedure. Examples of GE plants introduced under the notification procedure are those GE plants altered to be resistant to certain insects or herbicides. GE plants that do not meet the notification eligibility criteria and all other GE organisms, such as microbes and insects, must be introduced under the permit procedure in current § 340.4. In recent years, APHIS has processed most notifications and permits through its electronic, e-permitting system that is accessible by the internet at *http://www.aphis.usda.gov/permits/learn_epermits.shtml.*

In making a regulatory determination for a permit or notification for a GE organism subject to the part 340 regulations, APHIS makes such a determination on whether the actions under notification or permit are unlikely to result in the introduction or dissemination of a plant pest. This determination takes into account various risk factors, including, among other things, a low risk that the GE organism or its progeny can persist, reproduce, and establish without human assistance. Other risk factors that would support an "unlikely" determination would be minimal availability of suitable hosts or habitats for the organism and low risk that the organism may cause damage to plants and plant products.

Regarding the risk of introduction or dissemination of the GE organism as a plant pest, an "unlikely" determination takes into consideration both the nature of the organism (i.e., low risk that the organism or its progeny can persist, reproduce, establish, and spread without human assistance) *and* any additional mitigations that are placed upon the organism that restrict its movement and make its unauthorized introduction or dissemination unlikely.

The notification procedure was first added to the regulations in 1993, and then amended in 1997 to allow a broader range of plant species to be eligible for the procedure. The notification procedure was designed to be a streamlined procedure with the eligibility criteria and performance standards already built into the regulations. Over the past decade, APHIS has typically authorized 700–1200 notifications per year.

As part of the notification procedure, applicants must adhere to performance standards set forth by APHIS for proper confinement of the GE plants. The goal of proper confinement is to ensure that the GE plants do not persist in the environment. Under the notification procedure applicants provide information about the introduction sufficient for APHIS to evaluate eligibility for the procedure and impacts on the environment. This information includes information on the plant species, introduced gene(s), location(s), and anticipated time frame for the introduction.

For notifications, the eligibility criteria and the performance standards stated in the regulations must be met, but APHIS does not prescribe how the performance standards must be met. For example, one of the performance standards in § 340.3(c)(5) requires that "The field trial must be conducted such that (i) The regulated article will not persist in the environment, and (ii) No offspring can be produced that could persist in the environment." The responsible person might meet this standard in a field trial by isolating the regulated GE plants at a sufficient distance to preclude gene flow from the GE plant to sexually compatible plants in the vicinity. Another design protocol might meet the same performance standard by planting the GE plant at a time in the growing season when surrounding plants of the same species would not be biologically capable of being fertilized by pollen from the GE plant (temporal isolation).

The regulations in current § 340.3(e) specify that the APHIS notification procedure must be completed within 30 days for environmental release and importations and within 10 days for the interstate movement of a regulated article. If APHIS completes the review process and finds that all regulatory requirements have been met, the notification is authorized in a process termed "acknowledgement," and the applicant can proceed with the introduction under the terms of the notification. Notifications are valid for one year from the date of introduction.

Approximately 10% of APHIS authorizations are done under the permitting procedure. The permitting procedure, found in § 340.4 of the current regulation, describes the types of permits, information required for permit application, the standard permit conditions, and administrative information (e.g., time frames, appeal procedure, etc.). Permits include specific conditions that must be followed by the permit holder. Standard permit conditions are listed in the regulation, and APHIS can supplement these with additional conditions as necessary. The current regulations specify the amount of time that APHIS is allotted for review of complete permit applications: 60 days for permits for importation and interstate movement; 120 days for environmental release.

Some regulated articles are conditionally exempt from the requirement for permits when moved interstate under the conditions stipulated in the regulation. Conditional exemptions currently exist in the regulations for the interstate movement of certain GE bacteria (*Escherichia coli, Bacillus subtilis*), fungi (*Saccharomyces cerevisiae*), as well as the plant species *Arabidopsis thaliana*. APHIS established these conditional exemptions from interstate movement permit by amending the regulations in 1988 and 1990.

APHIS forwards the applications for all permits, and notifications, with any confidential business information redacted, to State regulators in the States to which regulated articles will be moved and/or in which environmental release is planned. This is done to notify States of the requested action and to allow States to review and comment on proposed releases or importations or movements.

The current regulations also include various provisions and prescribed standards for containers, marking, and identity that apply to shipments of regulated articles. For example, there are instructions regarding how to label containers of imported regulated articles with the nature of the contents, origin and destination, and other information, and detailed instructions on what materials (plastic, metal, etc.) and dimensions may be used for containers of regulated articles.

Under the current regulations, APHIS may also grant "nonregulated status" to a GE organism in accordance with the procedure described in § 340.6. A determination of nonregulated status means that the organism is no longer subject to the part 340 regulations, and therefore there is no longer any requirement for APHIS authorization under part 340 for a permit or notification when the GE organism is imported, moved interstate, or released into the environment.

C. Plant Protection Act Authority to Regulate Plant Pests, Noxious Weeds, and Biological Control Organisms

Under the provisions of the PPA, Congress has granted the Secretary of Agriculture authority to develop regulations in order to detect, control, eradicate, suppress, prevent, or retard the spread of plant pests or noxious weeds. The PPA grants the Secretary authority to regulate the movement into and through the United States of any plant, plant pest, plant product, biological control organism, noxious weed, article, or means of conveyance, in order to prevent the introduction or dissemination of *plant pests* and *noxious weeds*.

The current regulations were promulgated under former statutes, i.e., the FPPA and PQA, which provide USDA authority to regulate articles that present a risk of *plant pest* introduction or dissemination. In addition to the provisions of the FPPA and PQA, the PPA incorporates authority that previously was under the Noxious Weed Act of 1974. In order to best evaluate the risks associated with these GE organisms and regulate them when necessary, APHIS needs to exercise its authorities regarding noxious weeds and biological control organisms, in addition to its authority regarding plant pests.

The definition of plant pest in the PPA is broad and includes living organisms that could directly or indirectly injure, damage, or cause disease in any plant or plant product (7 U.S.C. § 7702(14)). Under the PPA, organisms which could be plant pests include:

- Protozoans
- Non-human animals
- Parasitic plants
- Bacteria
- Fungi
- Viruses or viroids
- Infectious agents or other pathogens
- Any article similar to or allied with any of the above articles.

The definition of noxious weed in the PPA includes:

> * * * any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment. (PPA § 7702(10))

An important distinction between noxious weeds and plant pests is that noxious weeds under the PPA are always plants or plant products. Plant pests are usually not plants (with the exception of certain parasitic plants such as dodder, striga, and witchweed), but are other types of organisms that harm plants.

III. Proposed Rule

A. Proposed Regulatory Scope (§ 340.0 Scope and general restrictions)

We propose to better align the regulations with the PPA authorities in order to ensure that the environmental release, importation, or interstate movement of GE organisms does not pose a risk of introducing or disseminating plant pests or noxious weeds. Although the current program has been effective in ensuring the safe environmental release, interstate movement, and importation of genetically engineered organisms, technological advances have led to the possibility of developing GE organisms that do not fit within the plant pest definition, but may cause environmental or other types of physical harm or damage covered by the definition of noxious weed in the PPA. Therefore, we consider that it is appropriate to align the regulations with both the plant pest and noxious weed authorities of the PPA.

1. Genetically Engineered Organisms Subject to 7 CFR part 340

We are proposing to revise the scope of the regulations in § 340.0 to make it clear that decisions regarding which organisms are regulated remain science-based and take both plant pest and noxious weed risks into account. The proposed scope of the regulations states that genetically engineered organisms whose importation, interstate movement, or release into the environment would be subject to the regulations are:

Genetically engineered plants if:

(i) The unmodified parent plant from which the GE plant was derived is a plant pest or noxious weed, or

(ii) The trait introduced by genetic engineering could increase the potential for the GE plant to be a plant pest or noxious weed, or

(iii) The risk that the GE plant poses as a plant pest or noxious weed is unknown, or

(iv) The Administrator determines that the GE plant poses a plant pest or noxious weed risk.

Genetically engineered non-plant, non-vertebrate organisms if:

(i) The recipient organism can directly or indirectly injure, cause damage to, or cause disease in plants or plant products; or

(ii) The GE organism has been engineered in such a way that it may increase the potential for it to be a plant pest; or

(iii) The risk that the GE organism poses as a plant pest is unknown, or

(iv) The Administrator determines that the GE organism poses a plant pest risk.

Under the current regulations, there is no explicit statement of the relative responsibilities of the Administrator and regulated parties in determining whether an organism met the definition for *regulated article* and therefore would be subject to the regulations. Under the proposed regulations, the responsible person for a GE organism could correctly apply the criteria in § 340.0 to determine whether the GE organism is subject to the regulations. Alternatively,

the Administrator could determine any GE organism to be regulated after determining that the GE plant poses a plant pest or noxious weed risk.

In many cases, it will be very straightforward for a responsible person to apply these criteria and determine that a GE organism is subject to the regulations. For example, the GE organism would clearly be subject to the regulations if the recipient organism were a plant pest or noxious weed. A GE organism would also clearly be subject to the regulations if there was little data or previous experience available concerning the recipient organism's plant pest or noxious weed potential, or the type of modification, with the result that it is difficult to do a reliable evaluation of the risks that the GE organism may be a plant pest or noxious weed.

In other cases, it may not be readily apparent to the responsible person for a GE organism whether or not the organism falls within the scope of § 340.0 and is regulated. For this reason, persons who are not sure about whether a GE organism falls within the regulations or who maintain that a particular GE organism is not subject to the regulations based on their belief that it is not an organism within the scope of § 340.0 may consult with APHIS.

A GE organism may be within the scope of the regulations based on the information available at the time of the determination, which is usually less information than is available when the Administrator evaluates, for example, whether a regulated GE organism should be considered for an exemption from the requirement for a permit, or should be considered for a determination of nonregulated status (see discussion of § 340.6 below regarding nonregulated status). In other words, this scope determination has one purpose (to determine whether regulation is necessary at all) and is based on one level of knowledge about a GE organism, while determinations regarding such things as necessary permit conditions or exemptions or nonregulated status have a different purpose and are based on a different level of knowledge about a GE organism.

It is important to note that while a GE organism may be within the scope of the regulations due to certain identified plant pest or noxious weed risks, it may also be within the scope of the regulations if there is not enough information about the GE organism's potential plant pest or noxious weed risks to make a decision regarding those risks. At the early stages of developing a GE organism, there may not be sufficient information available about the organism to clearly determine the potential associated plant pest or noxious weed risks. Unknown risks might lead to a determination by the Administrator that a GE organism should be subjected to regulatory oversight if APHIS lacks familiarity with the non-transformed recipient organism or the introduced trait.

The proposed scope makes it clear that the mere act of genetic engineering does not trigger regulatory oversight or mean that a GE organism will pose risks as a plant pest or noxious weed. Instead, it clarifies that APHIS would subject a GE organism to regulatory oversight based upon known plant pest and noxious weed risks of the parent organisms, or based upon the traits of the GE organism, or based upon the possibility of unknown risks as a plant pest or noxious weed when insufficient information is available.

Consultation With APHIS Regarding the Scope of These Regulations

The criteria described in the scope should help developers form a reasonable expectation as to whether their GE organism is within the scope of the regulations, based on the nature of the parent organisms, the engineered traits, and the amount of information available regarding the organism and similar organisms.

APHIS anticipates that initially the range of GE organisms that the Administrator may determine to be covered by the proposed regulatory scope will be broad. This will be due to both an initial measured implementation of the revised regulatory oversight as well as to the application of the scope criteria to the transformed organisms and recipient traits. Over time, the range of GE organisms subject to oversight is expected to decrease as APHIS becomes more familiar with these organisms and receives information from which it can reach a conclusion that these GE organisms or groups of organisms do not present increased or unfamiliar plant pest or noxious weed risks. Because the Administrator may make such a determination at any time the Administrator receives information that a GE organism is within the scope, APHIS expects that developers will seek early consultation with APHIS on whether the regulatory scope covers their GE organism. Since it is generally necessary for research or business plans to include, as early as possible, elements addressing regulatory processing, approval, and compliance, it will be in the interest of the developers to determine the regulatory status of their GE organism prior to contemplating its movement or environmental release. Therefore, APHIS will offer to consult with a developer of a GE organism regarding whether the GE organism is within the scope of the proposed regulations.

After consultation and review of available information, the Administrator will respond in writing as to whether the Administrator has determined that the GE organism is within the scope of the regulations. APHIS plans to make information publicly available by posting and maintaining information on its Web site about the determinations it makes pursuant to this consultation process to help the public and regulated entities understand which organisms are subject to the regulations.

We welcome suggestions from the public on the most appropriate ways to provide administrative guidance to the public on the issue of which GE organisms are within the scope of the regulations. The Agency is especially interested in ways which will balance transparency with the efficient use of Agency resources in conducting consultations and communicating information to the public regarding which GE organisms are within the scope of the regulations.

Organisms Specifically Excluded From the Scope of the Regulations

Specifically excluded from the proposed regulatory scope are GE microorganisms that are regulated as biological control organisms by the EPA under provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). APHIS concludes that there is no need for such GE organisms to be evaluated by both agencies. EPA is already evaluating the environmental safety of such organisms with respect to their impact on the entire environment, including plants. We also propose to retain an exclusion from the current regulations for GE microorganisms where the recipient microorganism is not a plant pest and which have resulted from the addition of genetic material from a donor organism where the material is well characterized and contains only non-coding regulatory regions.

Effect of Noxious Weed Authority on the Scope of the Proposed Regulations

The definition of noxious weed encompasses plants that pose risks akin to plant pests, because it includes "any plant or plant product" that can "injure or cause damage to crops * * * other interests of agriculture * * * or the environment", but also includes plants that can pose harm to non-plant organisms, such as humans. Therefore

evaluation of noxious weed risk expands what we can consider, while still including those risks examined under the plant pest approach. When considering risks associated with a GE plant, we would continue to consider whether it can harm plants, as well as whether it can cause the other types of physical harm or damage described in the definition for noxious weed.

The first consideration in determining if a plant is a noxious weed is identifying what direct injury or damage (physical harm) the plant causes. If direct harm or damage is established, the next consideration is to evaluate any indirect damage the plant may cause to interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment. In general, federally listed noxious weeds are plants that are likely to be aggressively invasive, have significant negative impacts, and are extremely difficult to manage or control once established.

The distinction between a weed and a noxious weed warrants emphasis. "Weeds," in the broadest sense of the word, could include any plant growing where and/or when it is unwanted; even plants that are desirable in some settings may be considered weeds in others. In a narrower sense, weeds are invasive, often non-native, plants which impact natural and managed ecosystems, often with significant negative consequences due to lost yields, changes in management practices, altered herbicide use, etc. Only a fraction of these problematic weeds are considered to be so invasive, so harmful, and so difficult to control that Federal regulatory intervention to prevent their introduction or dissemination is justified, and these are the focus of the regulatory controls placed on them by APHIS. However, any weed, and virtually any plant or plant product, can be evaluated by APHIS to determine whether its characteristics and potential impacts warrant its listing as a noxious weed.

APHIS currently lists 98 aquatic, terrestrial, or parasitic plant taxa as noxious weeds. The species included in the list illustrate the kinds of plants APHIS considers to be sufficiently invasive, damaging, and difficult to control to be deemed noxious weeds. Table 1 describes some specific examples from the Federal noxious weed list and the kinds of impacts noxious weeds can have, to illustrate the types of effects APHIS will be looking for when evaluating whether GE plants reviewed under part 340 have any potential noxious weed traits. The experience and precedents developed by the APHIS–PPQ noxious weed program provide a guide for the regulation of plants that may be noxious weeds, and we intend to apply it to the consideration of GE plants in the same way.

TABLE 1—EXAMPLES OF IMPACTS CAUSED BY FEDERALLY LISTED NOXIOUS WEEDS

Impact	Description of impact	Example species
Lost productivity of crop fields.	Noxious weeds may directly compete with crop plants for limited resources, dramatically reducing yields.	Cogongrass (*Imperata cylindrica*) infests over 20 crop species; it releases chemicals into the soil that suppress crop growth and causes damaging puncture wounds to plant roots, bulbs, and tubers. Other examples include Benghal dayflower (*Commelina benghalensis*), red rice (*Oryza* spp.), and kikuyugrass (*Pennisetum clandestinum*).
Parasitic damage to crops.	Parasitic plants can cause significant reductions in yield by attaching themselves to a host plant, removing nutrients and ultimately killing it.	Federally listed noxious parasitic plants include the dodders (*Cuscuta* spp.)—with common names like strangleweed, devil's-guts, hellbine, and witch's hair—and witchweed (*Striga* spp.), which causes devastating losses in corn, sorghum, and rice.
Reduced productivity of pasture.	Grazing animals may avoid noxious weeds and consume the more favorable pasture species, resulting in increased noxious weed populations at the expense of more favorable species. Noxious weeds may also outcompete desirable pasture species.	Serrated tussock (*Nassella trichotoma*) has heavily infested large areas, leaving them completely incapable of supporting livestock.
Injury to humans or livestock.	Many noxious weeds are toxic, harming humans or livestock either when consumed or by direct contact.	Cape tulip (*Homeria* spp.) contains a cardiac glycoside, which can be fatal to livestock. Contact with giant hogweed (*Heracleum mantegazzianum*) causes painful skin blisters. Three-cornered jack (*Emex australis*) and devil's thorn (*Emex spinosa*) both bear spiny fruits that can cripple or cause injury to livestock or other animals.
Unchecked overgrowth.	Noxious weeds may be capable of completely dominating the landscape and preventing the use of cultivated or pasture lands for agriculture.	Mile-a-minute vines (*Mikania cordata* and *M. micrantha*) can entirely smother fields and forests in a dense, tangled mass of vines. A single plant of the aquatic weed giant salvinia (*Salvinia* spp.) can blanket 40 square miles in 3 months, and produce an underwater mat 3 feet thick.
Physical obstructions.	Growth rate and habit of some noxious weeds may physically hamper the movement of livestock and humans, or interfere with navigation of waterways.	Certain mesquites (*Prosopis* spp.), jointed prickly pear (*Opuntia aurantiaca*), and African boxthorn (*Lycium ferocissimum*) form impenetrable thickets filled with thorns or needles, blocking the movement of grazing animals, injuring them or preventing access to food and water.
Disruption of water flow.	Aquatic noxious weeds may disrupt water flow, adversely affecting irrigation, drainage and flood control canals, city water intakes, and recreational water use.	Notable examples include hydrilla (*Hydrilla verticillata*), giant salvinia (*Salvinia* spp.), and Chinese waterspinach (*Ipomoea aquatica*). Dense mats of oxygen weed (*Lagarosiphon major*) can completely shut down operation of hydroelectric plants.

TABLE 1—EXAMPLES OF IMPACTS CAUSED BY FEDERALLY LISTED NOXIOUS WEEDS—Continued

Impact	Description of impact	Example species
Habitat alteration	Noxious weeds may severely alter water quality by changing oxygen and nutrient content, may dramatically lower local water tables, or could so significantly outcompete or overgrow other vegetation resulting in a complete ecological shift of the habitat.	Infestation of lakes and ponds with hydrilla (*Hydrilla verticillata*) can alter aquatic ecosystems so drastically that native plants are entirely eliminated, rendering the habitat unsuitable for fish and other wildlife.

As discussed above, APHIS' determination that a plant is a noxious weed is based on notable physical harm or injury caused by the plant. The elements of the noxious weed definition include a number of interests that might be damaged by noxious weeds including not only plants but irrigation, navigation, the natural resources of the United States, the public health, the environment and interests of agriculture. Often APHIS quantifies the physical harm or injury in terms of economic losses. Loss in commodity value due to the presence of noxious weeds in seeds, for example, is a consequence of the anticipated physical damage that would be caused if the seed containing a noxious weed were distributed and planted; the economic loss is never simply the result of market preference to have commodities free of certain noxious weed seeds in and of itself, in the absence of any potential physical damage or harm. APHIS does not consider significant economic effects alone that are not linked to physical damage to be sufficient to determine a plant is a noxious weed.

Certainly, some noxious weeds can cause physical harm to the health of humans or livestock and other animals. In general, these impacts occur when individuals come into direct contact with the noxious plants or plant parts, which may cause physical injury or are toxic or otherwise harmful when consumed. Conceivably, noxious weeds growing in crop fields could potentially threaten public health, for example, if toxic parts of the noxious weeds are harvested and inadvertently enter the food supply. If such toxic or otherwise harmful noxious weed parts were found in food and caused the food to be "adulterated" within the meaning of the FFDCA, FDA could take regulatory action against the food.

Whereas APHIS has no direct role in evaluating the safety of foods, the agency plays an important supporting role in safeguarding the food supply by protecting the health of plants and animals at the farm level. When evaluating whether a particular GE plant may be a noxious weed because it poses a public health risk when growing in the environment, APHIS considers toxicity and other food safety information, including the type reviewed by EPA and FDA. In the case of GE plants, APHIS would not assess the safety of the GE plant for human or animal consumption, but would consider available information about toxicity and other food safety information in assessing noxious weed risk posed by the plants growing in the environment.

It should be noted, moreover, that most GE plants that APHIS has been regulating in the past, such as varieties of GE corn and soybeans modified with common agronomic traits, do not qualify as "noxious weeds". But with the increasing diversity of both agronomic and non-agronomic traits being engineered into plants it is appropriate to place regulatory controls upon GE plants proportionate to the likelihood that they may present a noxious weed risk until the potential risk can be appropriately evaluated.

How Non-Plant, Non-Vertebrate GE Organisms Fall Within the Scope of the Regulations

The proposed revision of the regulations retains control for potential plant pest risks posed by non-plant, non-vertebrate GE organisms. We would continue to explicitly use the plant pest provisions of the PPA for regulating non-plant, non-vertebrate GE organisms which align with the taxa listed in the PPA definition of plant pest. In its reviews of GE non-plant and non-vertebrate species, APHIS will continue to assess GE insects, fungi, bacteria, and other non-plant, non-vertebrate organisms for their potential to pose risks as plant pests.

The scope of the regulations as defined above makes it clear that it is the Administrator, and not the public, who determines whether a non-plant organism is within or outside the proposed scope of the Part 340 regulations. APHIS welcomes public comment on the proposed concise criteria that the Administrator would consider when concluding that a GE organism is not a plant pest. We envision providing additional information on the Administrator's interpretation on such criteria at the time of the final rule or in subsequent administrative guidance.

GE Vertebrate Animals Do Not Fall Within the Scope of the Regulations

Although the PPA definition of plant pest includes the potential for a nonhuman, vertebrate animal to be considered a plant pest, APHIS decided at this time that there are no demonstrated risks or pending GE animal developments indicating that it is necessary for the proposed regulations to evaluate vertebrate GE animals as potential plant pests. Because other statutory authorities exist for addressing GE animals, APHIS could guard against any plant pest risks that might be presented by GE vertebrate animals without directly regulating them under the regulations in part 340. On the other hand, we propose to regulate GE invertebrate animals under part 340 because many classes of invertebrates include known plant pests (e.g., insects, arachnids, nematodes, gastropods, etc.).

How GE Biological Control Organisms (BCOs) Fall Within the Scope of the Regulations

The PPA defines biological control organism (BCO) as "any enemy, antagonist, or competitor used to control a plant pest or noxious weed" (7 U.S.C. 7702(2)). The PPA gives the authority to regulate plant pests and noxious weeds, not specifically biocontrol organisms. APHIS recognizes that BCOs may have the potential to affect populations of noxious weeds or plant pests, or become plant pests themselves. To fall within the scope of the proposed regulations, the GE BCO would have to pose a threat as a plant pest or noxious weed. There are relatively few examples today of GE BCOs, but these may become more common in the future. For example, some researchers are developing GE biological control pink bollworms that

are sterile, which achieve their controlling effect by reducing the ability of fertile, non-GE pink bollworms to produce offspring. Such GE pink bollworm BCOs would fall within the scope of the proposed regulation, because they are plant pests. Although there are currently no examples of using GE plants as BCOs, such a GE plant would be evaluated under the proposed regulations to evaluate whether it is a noxious weed or a plant pest.

Currently, the federal regulation of microbial BCOs is regulated by EPA under FIFRA, and this covers GE as well as non-GE microorganisms used to mitigate the effect of pests. Unlike the PPA, which limits the definition of BCO only to organisms used to control plant pests and noxious weeds, FIFRA covers microorganisms used as biological control for any pest. APHIS considers it duplicative to have these regulations include GE microbial BCOs under its scope since FIFRA already adequately covers them, so APHIS is proposing that the regulatory scope language in § 340.0(d) would explicitly exclude GE microorganisms if they are already being regulated as BCOs by EPA under FIFRA. We are proposing to only regulate GE BCO macro-organisms that fall under the proposed regulatory scope (APHIS–PPQ currently regulates the macro-organism non-GE BCOs used to control plant pests and noxious weeds pursuant to other regulations). APHIS welcomes public comment on this aspect of its proposal.

Intrastate Movements of GE Organisms Between Contained Facilities and Activities in Contained Facilities Do Not Fall Within the Scope of the Regulations

Under the current regulations, certain GE organisms are only regulated by APHIS if they are imported, moved interstate, or released into the environment. The regulations do not govern intrastate movements between contained facilities such as laboratories, nor do they govern such activities as creating GE organism in a contained research laboratory. The proposed revision does not change this aspect of the regulations.

2. Deleting the List of Organisms Which Are or Contain Plant Pests

In § 340.2 of the current regulations, there is a list of taxa that are considered to be plant pests. Under the proposed scope, this list is not needed because we would not use taxonomic classification of donor and recipient organisms to determine if a GE organism is regulated. When in the course of evaluating a GE organism APHIS considers whether a donor or recipient species is likely to be a plant pest or noxious weed, we would consider the most up-to-date pest information maintained by PPQ. This information is more specific than the information in the list of plant pest taxa in the current regulations, and should be more useful and reliable than static lists of taxa. APHIS welcomes public comment on deletion of the taxa list and preferred sources of plant pest and noxious weed information for use under the proposed regulations.

With deletion of this list from the regulations, there is also no longer a need for the procedure currently described in § 340.5 for amending this list.

3. Regulating Whole Organisms, Parts, and Nonliving Products

APHIS proposes to clarify the regulated status of nonliving plant products in the regulations. First, the PPA defines a plant pest only as any *living* stage of any of the articles specifically named in the plant pest definition that can directly or indirectly injure, cause damage to, or cause disease in any plant or plant product. Moreover, APHIS does not consider most GE organisms or parts of GE organisms which cannot reproduce to present a risk as plant pests or noxious weeds.

Conversely, we would regulate importation, interstate movement and release into the environment of GE seedlings, seeds, tubers, cuttings, bulbs, spores, etc., because there is a reasonable, albeit small, possibility of reproduction, establishment, and spread if these were deliberately or accidentally released into the environment without authorization.

Viable pollen from GE plants imported, moved interstate, or released into the environment would be subject to the regulations because such movements of pollen can reasonably lead to genomes becoming established in the environment. Similarly, in circumstances where an article incidentally contains viable pollen, during movement, APHIS would consider the movement regulated. There are many cases, however, when pollen may be present but is no longer capable of producing offspring, e.g., nonviable or immature pollen. In such cases, APHIS would not require permits under this part. The commercial distribution of cut flowers is one pollen movement situation that APHIS has considered in light of the regulations, especially in cases where the flowers are grown in other countries then imported only as cut flowers. APHIS considers these circumstances to pose little, if any risk, and therefore would not require permits for these activities.

The PPA defines a noxious weed as encompassing both plants and plant products. A plant product is defined as "any flower, fruit, vegetable, root, bulb, seed, or other plant part that is not included in the definition of plant; or any manufactured or processed plant or plant part." APHIS has regulated GE organisms under part 340 for over 20 years, and there is no strong evidence to suggest the need to regulate nonliving (nonviable) plant products in most cases. However, if in a specific case the importation, interstate movement, or environmental release of nonliving products of a GE plant may pose noxious weed risks, APHIS has clear authority to address those risks by imposing permit conditions on the handling of such nonliving products of the GE organism in the permit issued for the associated living GE organism. The proposed regulations state clearly in § 340.3(b) that the Administrator may also assign permit conditions addressing nonliving plant materials associated with or derived from GE organisms when such conditions are needed to make it unlikely that the nonliving materials would pose a noxious weed risk. APHIS invites consultation from any person considering a movement or release of nonliving materials derived from a GE organism who is uncertain as to whether it would be regulated.

B. Permits for Authorizing Importation, Interstate Movement and Release Into the Environment of Certain GE Organisms

1. Elimination of the Notification Procedure

APHIS first added the notification procedure to the regulations in 1993 as an administratively streamlined procedure for certain GE plants that met the eligibility criteria described in the regulation. Rather than using customized requirements, like the permit conditions used for the permitting procedure, the notification procedure uses generalized performance standards that are described in the regulation itself. The use of the performance standards that do not vary from one notification to the next is one of the ways that the more rapid administrative turnaround was achieved. In some ways, the term "notification" has been misleading to the public, since they do not realize that sending a notification does not mean automatic authorization by APHIS.

APHIS reviews notifications to verify that the GE plant meets the eligibility criteria, and also evaluates whether the

proposed importation, interstate movement or environmental release can be done in a manner that meets the performance standards described in the regulation. In many ways, these APHIS evaluations for notifications are very similar to those done for permit applications, but the notification procedure relies on applicants agreeing to meet the performance standards described in the regulation rather than submitting an application for APHIS review describing the specific measures they will employ for the activity (as is the case for permits). With permits, but not with notifications, APHIS can accept the proposed measures or add to them and the result is a set of binding customized permit conditions.

Because the notification procedure uses only the performance standards in the regulations, it is more administratively streamlined, but the general nature of the standards has made it difficult for APHIS inspectors to determine if a notification holder is in compliance and can also make enforcement more difficult. For example, under the current regulations, one of the performance standards for notifications relevant to environmental releases states that: "The field trial must be conducted such that (1) the regulated article will not persist in the environment, and (2) no offspring can be produced that could persist in the environment." Conversely, specific conditions which APHIS places on permits are unambiguous, easy to verify at inspection, and easier to enforce. A specific permit condition that could be used to address just part of the performance standard described above might read: "After final harvest of the GE corn plants covered under this environmental release permit, the site will be monitored every 4 weeks for the emergence of volunteer corn seedlings for one year, and any emerging volunteer plants will be devitalized before they produce pollen. Records of the monitoring and management of volunteers must be maintained by the permit holder and made available to APHIS upon request."

APHIS employs performance standards in many of its regulations, where appropriate. For example, we propose to employ a performance standard in another part of this proposal, container requirements for shipments of GE organisms. In that case, it is possible to employ a straightforward standard that the container must not break or leak when subjected to ordinary handling in transportation. The use of performance standards under the notification procedure has some benefits, such as providing the responsible person with flexibility in how the standard is met, e.g., allowing for appropriate change in protocols used during the growing season. However, there are some disadvantages in not specifically enumerating the specific measures that constitute compliance with the regulations. The permitting procedure does not have this disadvantage, because the permit conditions specify which actions need to be taken by the responsible person to be in compliance.

APHIS considered revising the performance standards and retaining the notification procedure, but this would not have remedied its shortcomings, especially the lack of specificity that is a necessity of using broadly applicable, performance standards in the regulations.

Under the proposed regulations where all authorizations will be done under a permitting procedure, the permit conditions will provide more specific information about what procedures the permit holder must follow in order to be in compliance. In the proposed rule, we are describing in detail the types of core permit conditions that will be imposed, plus the additional permit conditions that the Administrator can place upon the permit holder in order to make it unlikely that actions under the permit would result in the introduction or dissemination of a plant pest or noxious weed.

In view of the above discussion, APHIS has determined that it would have more flexible, risk-appropriate oversight, better regulatory enforcement and improved transparency if all regulated importations, interstate movements, and releases into the environment are authorized under the permitting procedure. The use of the permitting procedure in lieu of notifications is also necessary for APHIS to address some of the recommendations arising from the OIG Report and the provisions of the 2008 Farm Bill. For example, the OIG recommendations have led to proposed provisions in the regulations that will enable APHIS to add permit conditions to require additional reports during the course of an environmental release, the submission of notices to APHIS if the permit holder decides not to conduct the environmental release, and 7-day, pre-plant notices in the case of GE plants engineered to produce pharmaceutical or industrial substances. The last recommendation is already being implemented as a permit condition, because all of these authorizations are done under the permitting procedure. The OIG recommendations cannot be implemented under the notification procedure, because under the current regulations APHIS does not have the ability to attach conditions to notifications. This provides additional justification for APHIS to propose the elimination of the notification procedure. The APHIS proposal to eliminate the notification procedure is an effective way to address several of the provisions of the Farm Bill, such as the changes to the requirements for recordkeeping and reporting.

2. Revisions to Permit Procedures

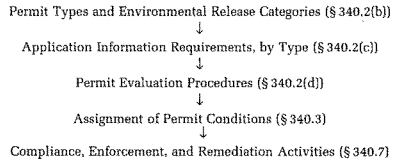
APHIS proposes to reorganize the regulations to improve the clarity of the permit application and evaluation procedures. The proposed change is more a reorganization than substantive change, and should enhance the transparency of the regulations to the public. The permitting procedure will continue to identify and obtain information relevant to evaluating the risks associated with a proposed importation, interstate movement, or release into the environment, and determine and document whether, and under what conditions, the activity should be allowed. The proposed regulations related to the issuance of permits are divided into two sections. The first is proposed § 340.2, *Procedure for permits*, which describes permit types, the procedure for permit application (including information requirements), and the Agency's administrative actions for permits. The second is proposed § 340.3, *Permit conditions*, which describes the general types of conditions that APHIS may add to a permit, and the obligations of the responsible person after permit issuance.

APHIS is proposing explicit procedures for amendment, transfer of responsibility, and revocation of permits in order to establish clear regulatory procedures that can increase efficiency yet maintain adequate safety. Currently the APHIS administrative practices to amend, transfer, and revoke permits have not been explicit in the regulation, and this addition will provide increased transparency and efficiency.

The proposed changes organize the regulations to more clearly reflect the procedural steps in the application, evaluation, and issuance of a permit (see Figure 1). First, the different types of permits (importation, interstate movement, and environmental release) are described in § 340.2(b), as are new subcategories of environmental release permits. Second, the types of information that must be submitted with a permit application are described in § 340.2(c). The permit type, as well as

the nature of the environmental release (if the permit is for a release), affect the application information requirements. Third, § 340.2(d) outlines the procedural and administrative steps of issuing a permit. Finally, the attachment of conditions to permits, which is also dependent upon permit type and release category, is described in § 340.3. Each of these permit-related sections of the proposed regulations is discussed below.

Figure 1. Schematic of activities associated with issuance and enforcement of permits, showing associated sections of the proposed regulation.



3. Permit Types and Environmental Release Categories (§ 340.2(b))

As discussed above in the background section, APHIS currently uses two procedures—notification and permits—to authorize the importation, interstate movement and release into the environment of GE organisms considered to be regulated articles under this part. The permitting procedure can be used for all regulated articles, but the notification procedure can be used only for certain GE plants that meet the eligibility criteria described in the regulations. Whereas permits are issued with explicit permit conditions which must be met by the permit holder, notifications have generalized "performance standards" described in the regulation and therefore do not vary from one notification to the next. Currently, approximately 90% of APHIS authorizations are done under the notification procedure.

Under the proposed system, which would eliminate notifications, APHIS would continue to issue three types of permits—interstate movement, importation, and environmental release. The procedures for the first two types of permits are relatively straightforward, and the conditions usually required for these permits address risks that are very similar from one shipment to another. We propose only minor adjustments to the procedures for interstate movement and import permits. In general, deliberate release of GE organisms into the environment presents a greater risk of introducing or disseminating plant pests and noxious weeds, and thus requires more careful oversight, than shipments of GE organisms into and across the country in secure containers. Of the three permit types, only environmental release permits would be differentiated into broad risk-related categories by the Administrator. This categorization would occur prior to the detailed and specific APHIS evaluation of an individual permit application. Table 2 summarizes the relationship of the three permit types and categories that pertain to environmental release permits.

TABLE 2—PROPOSED PERMIT TYPES AND CATEGORIES FOR ENVIRONMENTAL RELEASE PERMITS

Type		Use
Importation permit		For securely moving a GE organism into the United States.
Interstate Movement		For securely moving a GE organism from any State into or through any other State.
Environmental Release:*	Release Category A	For releases into the environment, outside the constraints of physical containment that are found in a laboratory, contained greenhouse, fermenter, other contained structure, or secure shipment.
	Release Category B	
	Release Category C	
	Release Category D	
	Release Category E (non-plants)	

*In some cases, an environmental release permit may also incorporate permits for importation or interstate movement when such movements are incidental to the environmental release.

The proposed sorting system for environmental release permits includes five categories: Four for releases of GE plants (Categories A–D) and one for releases of all other GE organisms (Category E). Releases of GE non-plant organisms (Category E) would be placed into a single category and reviewed on a case-by-case basis. APHIS considered the creation of smaller risk-related subcategories for non-plants, but APHIS has received too few permit applications to warrant the creation of these smaller groupings. Releases of plants would be grouped into four categories, as described below.

APHIS considered a tiered permitting system which would sort proposed environmental releases of plants into a number of risk-based categories. Lowest risk releases would be assigned to Tier 1, slightly higher risk releases in Tier 2, and so on. In such a system, tier assignment is analogous to a risk rating. In developing the specifics of implementing such a system in the regulations, however, APHIS found that it was challenging to pre-assign all conceivable releases into tiers representing discrete levels of risk. There are a large number of risk factors that contribute to the overall risk associated with any given release. These factors include reproductive biology and growth habit of the species, potential for gene flow to other species, phenotype engineered into the organism, familiarity with the genetic material used, safety of any expressed products, scale of the release, location, duration, experience, and compliance history of the applicant, proximity to threatened

and endangered species, and other factors.

Sorting proposed releases considering all relevant factors would lead to an unwieldy system with many risk-based categories, and would essentially require a full risk assessment prior to assigning a proposed release to the appropriate risk category. Consequently, it would be nearly impossible for applicants and the public to predict the risk tier to which a proposed release would be assigned.

APHIS proposes that the permitting system for environmental release permits would assign releases into administrative categories based upon two primary risk-related factors described below, so that the categories would identify the general types of releases of plants which share broadly similar risks and management issues. This initial administrative sorting would be followed by an evaluation that fully characterized the risk of the proposed release, which would then be the primary basis for adding necessary permit conditions. APHIS concludes that such a system could appropriately sort most releases into groupings that are alike enough that they could usually be treated similarly initially, in terms of application information requirements and evaluation of potential risks. In most cases the initial groupings would also result in a similar level of oversight of the release and conditions attached to the permit-but any final determination of the permit category, oversight and permit conditions would depend on the results of the APHIS evaluation.

Using this approach, there is no prior conclusion that every release within the same category poses the same level of risk. Likewise, releases in different categories do not necessarily pose greatly different risks. For this reason, APHIS would not refer to these groupings as "tiers," as this implies an incremental increase in risk from tier to tier, but would instead label them as "categories" which are lettered and not numbered.

APHIS developed the proposed sorting scheme by first examining the types of releases that typically are authorized under its current regulations. APHIS then modified the categories to make them more explicitly connected to plant pest and noxious weed risks.

The two primary factors APHIS identified as most relevant to define its sorting system for environmental release permits were the (1) ability of the unmodified recipient plant species to persist in the wild and (2) potential of the engineered trait to cause harm, injury, or damage, as described in the definitions of plant pest and noxious weed. Secondary factors, which in some instances may change the initial categorization, include: how the recipient plant is commonly used (e.g., as a food or feed crop); the impact of the engineered trait on the fitness of the GE plant; and, the degree of uncertainty associated with the trait and its possible impacts.

Regarding the persistence factor, APHIS proposes to group plant species according to the risk of persistence of the plant or its progeny in the environment without human intervention. Based upon the growth habit of the plant species and presence of wild relatives in the United States, APHIS proposes to sort all plants into four groups, listed in order of increasing persistence risk:

- *Low:* Populations of the recipient plant are unlikely to persist in the environment without human intervention, and the recipient plant has no interfertile wild relatives in the United States. Examples include corn, soybeans, and cotton (except in certain areas).
- *Moderate:* Populations of the recipient plant are known to be weakly persistent in the environment without human intervention, or the recipient plant has interfertile wild relatives in the United States. Examples include alfalfa, beets, canola, rice, and tomato.
- *High:* Populations of the recipient plant are known to be strongly persistent in the environment without human intervention, or the recipient plant has interfertile wild relatives in the United States which are aggressive colonizers. Examples include creeping bentgrass, poplar, sorghum, and sunflower.
- *Severe:* The recipient plant is a Federally-listed noxious weed or is known to be similarly aggressive in its ability to colonize and persist in the environment without human intervention. Examples include hydrilla and kudzu.

These aspects of plant biology and growth habit are broad indicators of the increasing likelihood that the plant or its progeny can reproduce and spread without human intervention. "Interfertile wild relatives" includes both wild relatives in the traditional sense, as well as feral populations of the same species persisting outside agroecosystems. The distinction between "weakly persistent" and "strongly persistent," is intended to mean survival without human intervention for one or very few generations (weakly persistent) versus several to many generations (strongly persistent). APHIS will clarify which species fall into each group by publishing lists in guidance.

Similarly, with regard to the factor for potential harm caused by introduced traits, APHIS proposes to group traits engineered into plants into four simple groupings based upon the definitions of plant pest and noxious weed. The groups are listed in order of increasing potential hazard of the engineered trait:

- *Low:*
  - Any new proteins or substances produced are unlikely to be toxic or otherwise cause serious harm to humans, vertebrate animals, or invertebrate organisms upon consumption of or contact with the plant or plant parts; and
  - No morphological changes which could cause mechanical injury or damage; and
  - Introduced sequences are known not to result in plant disease, and confers no or very low increased disease susceptibility.

An example would include expression of well characterized proteins known not to be toxic or harmful, such as a marker gene that does not pose a food or feed safety concern, or expression of viral genes where it is demonstrated that no protein is produced

- *Moderate:*
  - Any new proteins or substances produced are unlikely to be toxic or otherwise cause serious harm to humans or vertebrate animals upon consumption of or contact with the plant or plant parts ; or
  - Novel resistance to the application of an herbicide; or
  - Has novel ability to cause mechanical injury or damage; or
  - Produces proteins or substances that are associated with plant disease that are not prevalent or endemic in the area of release, or that confer an increased susceptibility to disease.

Examples include expression of new CRY proteins, ,mechanisms of herbicide tolerance (e.g., CP4–EPSPS, which confers glyphosate tolerance), and production of viral movement proteins.

- *High:*
  - Any new proteins or substances produced may be toxic or to otherwise cause serious harm to humans or vertebrate animals, upon consumption of or contact with the plant or plant parts; or
  - Produces an infectious entity which can cause disease in plants.

Examples include mercury hyper-accumulators or production of some pharmaceutical compounds.

- *Severe:*

Any new proteins or substances produced are known or likely to be

highly toxic or fatal to humans or vertebrate animals, upon consumption of or contact with the plant or plant parts.

These aspects of the engineered trait are related to harms or damages associated with plant pests or noxious weeds. This takes into consideration (1) the harmfulness of any substances produced, (2) the possibility of creating morphological changes that would cause physical injury, and (3) the likelihood of increasing plant disease, either due to risk of creating novel pests or increased inoculum source. Novel resistance to an herbicide is included in the "moderate" category due to the impacts the trait could have on the ability to manage the plant or its progeny.

The proposed use of plant growth habit and trait harm or injury as the two main factors for the initial sorting of environmental releases into categories uses the two factors to roughly approximate "exposure" and "hazard," respectively. Thus, using a combination of these two factors alone, we propose the following initial sorting of plant-trait combinations into release permit categories (see Table 3). Once environmental releases of GE plants have been sorted into the permit categories shown in Table 3, we will review and evaluate the information submitted by the applicant to determine oversight and permit conditions. The information requested from applicants will not be limited to these factors and is, in fact, designed to allow us to evaluate any of the risks associated with noxious weeds and plant pests. In some instances, our review may result in a change to the release category assignment of a GE plant.

TABLE 3—INITIAL SORTING INTO ADMINISTRATIVE PERMIT CATEGORIES (A, B, C, AND D) FOR ENVIRONMENTAL RELEASES OF GE PLANTS, BASED UPON PERSISTENCE RISK OF THE RECIPIENT PLANT SPECIES AND POTENTIAL HARM OR DAMAGE OF THE ENGINEERED TRAIT

Persistence*	Potential harm or damage of engineered trait			
	Low	Moderate	High	Severe
Low	A	A	C	D
Moderate	A	B	C	D
High	B	B	C	D
Severe	D	D	D	D

*Persistence risk of the recipient plant species.

The sorting system above presumes that there is sufficient scientific information available about the GE plant to support the categorization. For example, the phenotype conferred by inserted sequences and the growth habit of the plant species in the U.S. must be well-characterized and based upon direct empirical observation of the genetic construct in the recipient plant species. In cases where less (or nothing) is known about phenotype of the engineered trait in the recipient plant species-such as inference based upon sequence similarity, protein structure modeling, or observation of the genetic construct in other species-the release category may be changed (from A to B or B to C) as a result of this uncertainty. Similarly, lack of familiarity with the plant species' behavior in the U.S. or the techniques needed to mitigate the likelihood of its persistence could also change the release category.

APHIS considered whether to adjust the categories table to acknowledge that an engineered trait could affect (enhance or detract from) the other factor axis, namely the persistence risk of the nonmodified recipient plant. Engineered traits such as resistance to biotic or abiotic stresses could theoretically increase the fitness of the plant, and thereby increase the likelihood that it will persist in the environment without human assistance. Considering the range of persistence risks posed by all of the different plant species sorted into any one of the proposed groupings, however, APHIS has concluded that in most instances the engineered trait would not alter the likelihood of persistence enough to warrant a change in initial release category. However, in cases where the engineered trait significantly alters plant growth habit, metabolism, or reproduction to increase the likelihood of persistence in the environment, APHIS could change the release category accordingly. Examples of such changes might include converting an annual species to a perennial or converting a plant with C3 metabolism to crassulacean acid metabolism (CAM).

The proposed category system should provide a simple, transparent way for APHIS review information in applications to initially sort releases into broad, risk-related categories, which can then be more efficiently assessed for the actual risks posed by the release. However, it should be emphasized that the categories are intended only for initial sorting, and other factors are taken into account in the APHIS evaluation when determining the specific permit conditions.

APHIS intends that release Category A will be associated with a level of regulatory oversight similar to environmental release notifications under the current system, and Categories B and C with a level of regulatory oversight similar to various permits that have been issued under the current system. However, it will be much clearer to the public what types of oversight will be applied broadly within each category. As we discussed above, oversight and permit conditions with each category will be similar, though not necessarily identical, for any plant within the category. Category D was created to acknowledge the possibility that some proposed releases may pose a very high risk of introducing a highly persistent or harmful plant into the environment. To date, APHIS has never been requested to allow releases that would fall into this category. If an applicant were to propose a Category D release, APHIS would only authorize such releases after imposing extremely strict levels of oversight akin to high security quarantine far exceeding that of Category C that would ensure that the GE plants could not persist in the environment. The information requirements, permit conditions, and general levels of oversight associated with each release Category are discussed below.

This simple sorting system places GE plants into categories and provides a relatively clear, simple rationale for placement in a given category. What follows is a series of illustrations of common plant-trait combinations and the release categories to which they would be assigned:

- *Category A:*
  - Bt corn producing CRY1ab toxin. The plant is unlikely to persist in the

environment and the safety of the protein has been assessed by the EPA.

○ Soybeans engineered with glyphosate tolerance conferred by CP4–EPSPS. While herbicide tolerance poses a "moderate" hazard, soybean has no interfertile wild relatives in the U.S..

• *Category B:*

○ Corn producing a new CRY protein. The plant is unlikely to persist and the novel CRY protein is likely to be toxic to some species that live or feed on the plant (normally Category A), but its food/feed safety is only inferred from similarity to other CRY proteins.

○ Random "knock-out" or antisense libraries of soybean lines. While the lines may not likely produce novel proteins or substances (Category A), because of the uncertainty associated with the impacts of genetic engineering on these lines, they would be treated as Category B. Well-characterized lines taken from such libraries that do not produce new proteins would likely be treated as Category A.

○ Kentucky bluegrass engineered with glyphosate resistance conferred by CP4–EPSPS. Herbicide resistance is a "moderate" hazard and bluegrass has interfertile wild relatives in the U.S.

○ Pines producing an enzyme to enhance paper production. Pines are persistent and have interfertile wild relatives in the United States.

• *Category C:*

○ Poplar engineered to produce enzymes for heavy metal bioremediation.

• *Category D:*

○ Any Federally listed noxious weed that has been genetically engineered; any GE plant producing a vertebrate toxin.

Permits for Environmental Releases of Plants Making Pharmaceutical and Industrial (PMPI) Compounds

APHIS considered whether to continue to issue environmental release permits for GE plants engineered to produce pharmaceutical and industrial compounds if the GE plant species is the same as, or sexually compatible with, a species commonly used for food or feed. APHIS concludes that the proposed permitting procedure and the use of stringent permit conditions can continue to effectively minimize the risks that may be associated with the environmental release of such GE plants. APHIS will continue to impose permit conditions that take into account the issues related to the safety of proteins or other substances that these plants have been engineered to produce. Based upon APHIS experience to date, many releases of GE plants producing pharmaceutical or industrial substances would fall in Category C, and would carry the same level of oversight as current permits for PMPI.

4. Permit Application Information Requirements (§ 340.2(c))

In the proposed regulations, we provide greater detail about the basic application information requirements that need to be addressed in all permit applications, as well as additional basic information required for each permit type and the categories in the case of environmental release permits. Under the current regulation, certain areas where APHIS routinely needs information from the applicant do not become apparent until the applicant submits the permit application (and APHIS subsequently follows up for additional information). Some of the information requirements related to recordkeeping, reporting, and contractual arrangements among the permit holder and agents are new to the regulation and reflect, in part, certain provisions of the 2008 Farm Bill and also align with recommendations of USDA's OIG 2005 Report. For example, the OIG recommendations have led to provisions that will enable APHIS to require geographic coordinates for the locations of environmental releases.

The differences between the information required for an application under the current regulations versus the proposed regulations may be seen by comparing current § 340.4 to proposed § 340.2(c). Both the current and proposed application procedures require information characterizing the nature of the GE organism, including detailed molecular biology information about the expression of the introduced genetic material. They also both require information about the type of movement and/or release planned. The proposed rule requires more detail in some of these areas, and more description of the applicant's plans and methods to prevent unauthorized releases, and to respond to unauthorized releases if they occur. This information is used in part by APHIS to formulate the specific permit conditions. In cases where the permit is for environmental release, and would be in permit categories C or D according to the table in § 340.2(b)(3), a greater level of detail would be required for almost all aspects of the activity, including the recipient organism, the inserted gene(s), site location and management practices, and training and communication among the permit holder and agents involved in the activity covered under the permit. This information would also address the capability of the organism to persist or spread in the environment, or include details about how the engineered traits might be harmful.

5. Permit Conditions (§ 340.3)

Conditions are specific practices or requirements that an applicant must follow upon issuance of a permit. Under the current regulation, the permit conditions are described in the same section as the permit procedure itself. In the proposed revision, the permit conditions are enumerated in a separate section (§ 340.3) to accommodate the additional details to describe conditions for the three permit types as well as the categories of environmental release permits.

The use of permits and permit conditions gives APHIS and the responsible person a clearer understanding as to what actions must be taken for the permit holder to comply with the regulation. In the proposed regulation, APHIS has strived to provide as much transparency and predictability as possible about permit conditions while retaining sufficient flexibility so that the regulations will be adaptable in a broad range of cases.

Permits will be issued with the core permit conditions described in § 340.3(a), which are a minimum set of basic conditions for importation, interstate movement, and release. The Administrator may add to these conditions additional or expanded conditions when necessary to make it unlikely that actions under the permit would result in the introduction or dissemination of a plant pest or noxious weed.

The Administrator will assign the permit conditions in a manner that is commensurate with the risk of the individual proposed movement or release. Additional or expanded permit conditions may include, but are not limited to, specific requirements for: reproductive, cultural, spatial, temporal controls; monitoring; post-termination land use; site security or access restrictions; and management practices such as training of personnel involved in the release.

The proposed description of permit conditions elaborates on the "standard" permit conditions found in the current regulations, and the additional detail is designed to better communicate with potential applicants what the requirements are likely to be for their particular permit, and will better support administration of the program, including compliance and enforcement.

In the current regulation, only "standard" permit conditions are described, and APHIS has the authority to place other conditions upon the permit as deemed necessary by the

Administrator. The proposal for permit conditions will be more transparent to the public and this transparency will better facilitate planning by researchers, especially those who have not previously received permits from APHIS.

The proposed required core permit conditions consolidate six primary areas addressed in different parts of the current regulations to ensure compliance with the regulation and to make it unlikely that the permitted activity will result in the introduction and dissemination of a plant pest or noxious weed: Identity, shipment, unauthorized dissemination, communication and training, records, reports and notices. APHIS intends the list of specific condition areas we propose in § 340.3 to be used for all permits we issue as they apply to importation, interstate movement, and release into the environment. The required permit conditions listed in § 340.3 represent the permit conditions that we propose to apply for any type of permit. Listing them in the regulations should provide applicants with the ability to plan their activities with knowledge of the primary requirements for all activities that would have to be met to comply with the regulations.

For environmental release permits, proposed § 340.3(a)(4)(iii)(F) would also require the permit holder to notify APHIS seven days prior to initiation of the release if the release is Category C or D. For all Categories, permit holders are required to notify APHIS if they do not conduct the release.

The current regulations require environmental release permit holders to submit field test reports to APHIS within 6 months after termination of a field test. Under proposed § 340.3(a), the requirement simply states that the responsible person shall submit reports to APHIS at the times specified in the permit conditions and containing the information specified in the permit conditions.

APHIS is also proposing revision of the regulations to clarify the procedure it would use for amendment of permit conditions, transfer of a permit to a different responsible person, and revocation of an existing permit. Each of these additions to the regulations reflect current administrative practices and the incorporation of these into the regulations will make the overall system more transparent.

Currently, APHIS attaches conditions to permits at the moment the permit is issued to the applicant. Under the current regulations, the permitting procedure does not include a formal acknowledgement from the applicant prior to permit issuance that they are aware of and consent to the permit conditions. To verify that applicants are aware of and willing to abide by the conditions, APHIS proposes to add an additional administrative step in the permit procedure in § 340.2(d)(6) to support administration of the program. We are proposing to require that applicants agree prior to permit issuance that they will comply with all the permit conditions. Eventually, APHIS would build this feature into the existing ePermits system, and in the interim it would provide alternative mechanisms, such as e-mail communications, to implement this step of the permitting procedure.

APHIS is also proposing to clarify in § 340.2(h) of the regulations the procedure to be used when amendment of existing permit conditions is sought by the responsible person or required by APHIS, as well as the procedure for transfer of an existing permit to a different responsible person.

As with the current regulations, APHIS is retaining the flexibility to modify permit conditions as needed under individual circumstances. Proposed § 340.3 will increase transparency, yet still allow sufficient adaptability of the regulations for the full range of permit applications APHIS expects to receive today and in the future. APHIS recognizes that transparency and predictability for applicants must be balanced with maintaining Agency flexibility and adaptability for years to come under these regulations. APHIS encourages the public to comment on the choices we are proposing here, and we welcome suggestions for alternative approaches.

APHIS is proposing to revise the current sections of the regulations for container requirements for shipments of GE organisms (§ 340.8) and marking and identity requirements for imports of GE organisms (§ 340.7). Rather than the highly prescriptive approach in the current regulation, we will use an approach that is performance based and can be adapted to the activity that is being performed. This should provide greater efficiency for the public as well as APHIS, yet still achieve the necessary level of containment during shipments. We have reorganized this information in the regulations so that the requirements are associated with the related activity under the proposed regulation. For example, the shipping requirements for interstate movements under the conditional exemption have the requisite shipping conditions stipulated in the section for conditional exemptions. Likewise, the shipping conditions for import and interstate movement permits have been placed in the section for permit conditions, rather than retaining them in a separate section as in the current regulations. The performance-based standards we are proposing incorporates a simple performance standard in our proposed definition of secure shipment, discussed below: "Shipment of a package of sufficient strength and integrity to withstand leakage of contents, shocks, pressure changes, and other conditions incident to ordinary handling in transportation." APHIS is also proposing to require applicants to provide their proposed methods of secure shipment, and APHIS will specify the methods of secure shipment as a permit condition.

APHIS proposes to eliminate the marking and identity requirements for imports of GE organisms as a separate section of the regulations (current § 340.7). As with the container standard issue discussed above, appropriate labeling and related requirements would be highly individual depending on the organism, type of permit, and other conditions.

APHIS is proposing to include relevant tribal officials when it provides copies of permit applications to state regulatory officials. The current regulations state that APHIS provides this information to state regulatory officials.

6. Elimination of Courtesy Permits

APHIS is also proposing to eliminate the issuance of courtesy permits. Courtesy permits have been part of the regulations since their inception in 1987, but in an effort to better allocate APHIS resources, APHIS is proposing to remove this regulatory feature. The current regulations provide the ability for APHIS to issue "courtesy permits," in order to facilitate the movement of organisms which are outside the scope of these regulations, but whose movement might otherwise be hindered because of their similarity to organisms regulated under these regulations. The issuance of courtesy permits has generated confusion in the public and especially in the research community. The application form for courtesy permits is identical to the application for other types of permits, and the courtesy permit itself looks like other permits. This has led to the widespread misunderstanding by some researchers that courtesy permits are actually required for the movement of certain organisms, or that issuance of a courtesy permit removes the requirement for applicants to have other authorizations which may be required, under plant

pest regulations such as those found at 7 CFR part 330. APHIS commits significant resources to the issuance of these courtesy permits for the movement of organisms which are not subject to the provisions of part 340. APHIS will work with researchers and relevant government regulatory officials to facilitate the transition.

APHIS will also be available for consultation by persons who formerly used courtesy permits and other persons moving similar non-regulated articles, to discuss how to facilitate their movement. We also encourage the public to comment on the proposed elimination of courtesy permits and how APHIS should work with persons moving organisms for which we might formerly have issued courtesy permits.

C. Conditional Exemptions From Permit Requirement (§ 340.4)

The PPA allows the Secretary to create "exceptions" to the permit requirement when the Secretary deems that a permit is not necessary. That is, these regulated activities are allowed, under certain conditions, without seeking prior authorization via permit. The current APHIS regulations contain such PPA exceptions, but they are referred to as "exemptions" in the regulations. The current regulations include conditional exemptions from the requirement for interstate movement permits. These conditional exemptions were established in the regulations during the first few years after the regulations were first promulgated. The last conditional exemption was established in the regulations in 1990 for the interstate movement of GE plants of the species *Arabidopsis thaliana* as long as the conditions described in the regulations are met.

In its proposed revision to the regulations, APHIS is retaining the existing conditional exemptions from interstate movement. We are also proposing a new regulatory procedure that would enable APHIS to approve new conditional exemptions more efficiently than using the procedure of notice and comment rulemaking for each individual exemption. This can be a transparent and efficient way to provide regulatory relief. This new procedure for approving conditional exemptions is described in § 340.5, and it incorporates transparent steps including scientific review, public input, and adaptability when APHIS establishes the conditions relevant to the specific conditional exemption. Conditional exemptions, by their nature, will always include conditions and continued APHIS oversight to ensure that the conditions are met.

The current regulations provide for conditional exemptions from the requirement for permits for the interstate movement of certain GE strains of the microorganisms *Escherichia coli, Saccharomyces cerevisiae,* and *Bacillus subtilis,* and the plant *Arabidopsis thaliana* in § 340.2(b), and these conditional exemptions are being retained under the proposed regulations. Conditional exemptions from permit have been part of the regulations since the first exemption was established in 1988 (for the interstate movement of certain GE microorganisms), with the addition of another conditional exemption, through rulemaking, in 1990 for certain types of GE *Arabidopsis thaliana,* one of the most commonly used plants for scientific studies and which is frequently distributed among researchers. The essential conditions for each of these conditional exemptions address the following: (1) Species of the GE organism, (2) the types of genetic modifications that are allowed or prohibited for the GE organism, and (3) the manner in which the GE organism is shipped interstate. The existing conditional exemptions for the interstate movement of microorganisms were based on APHIS' conclusion that the exemption from the requirement for permits for interstate movement of these microorganisms would "not present a risk of the introduction or dissemination of a plant pest" (53 FR 12910, p.12910).

The existing conditional exemptions for *E. coli, Bacillus subtilis, Saccharomyces cerevisiae* and *Arabidopsis thaliana* are being retained in the proposed regulations. APHIS has no information that would indicate that such conditional exemption would be result in the introduction and dissemination of a plant pest or noxious weed. The text of the conditional exemption is being updated to place the shipping requirements with the other conditions associated with the exemption, instead of the current regulatory organization that has the shipping requirements in a separate section of the regulation.

In addition to the existing conditional exemptions, APHIS is proposing a transparent and efficient petition procedure in § 340.5 whereby the Administrator may approve additional conditional exemptions from permit without having to amend the regulations. This procedure would provide for a scientific review by APHIS as well as the opportunity for public review and comment on the scientific basis for the proposed exemption and the conditions associated with the exemption. The proposed procedure would provide an adaptable means of ensuring that the regulatory oversight is proportional to the risks posed by specific activities with GE organisms.

Proposed § 340.5 describes the procedure whereby a petitioner would seek a determination by the Administrator that the importation, interstate movement, and/or release into the environment of a GE organism is not subject to the requirement to have a permit under this part. We propose that the Administrator's decision to approve an exemption would be based upon a determination that the exemption from the requirement for a permit, when conducted with the associated conditions, is unlikely to result in the introduction or dissemination of a plant pest or noxious weed. APHIS anticipates that creating this new petition procedure to allow approval of additional conditional exemptions would enhance its ability to customize regulatory oversight to be proportional to any risks associated with importation, interstate movement, or release into the environment of a GE organism.

Under the proposed procedure, petitioners have the flexibility to propose various types of conditional exemptions from the requirement for a permit: The proposal can be for one or more permit types (importation, interstate movement, or release into the environment). In addition, the petitioner can propose the relevant conditions. The Administrator may approve the proposed conditional exemption as submitted in the petition, or the Administrator may impose alternatives to the requested exemption and conditions. The Administrator would review the scientific information and evaluate potential risks relevant to the proposal, then make the relevant documents (proposal and any supporting information) available to the public for review and comment prior to the Administrator's decision.

The information needed for a petition for conditional exemption would depend on the nature of the exemption requested and the proposed conditions for exemption. For example, conditional exemptions for the interstate movement of narrowly-defined groups of organisms with restrictive associated conditions might require considerably less information to justify than exemptions for broadly defined groups of organisms or less restrictive associated conditions. In making its determination, APHIS would consider all relevant information, including information in the scientific literature, copies of unpublished studies, and reviews by other regulatory agencies.

APHIS foresees many advantages to the proposed procedure, including scientific rigor, public involvement, and regulatory efficiency. APHIS would continue to provide to the public the relevant scientific information under consideration, its environmental analysis, and the rationale for its determination. The public would also retain its ability to provide comments to the agency prior to a decision approving a new exemption. APHIS decisions regarding these newly approved conditional exemptions would be published in the **Federal Register** and maintained on a list accessible to the public.

In evaluating whether to approve a new conditional exemption, APHIS would carefully consider issues related to enforceability of the conditional exemption when proposing to approve a conditional exemption. Unlike permit conditions, which are binding on the specific responsible person, the conditions associated with the exemption would apply to anyone who conducts the activity under the conditional exemption. Before granting such a conditional exemption, APHIS would take into consideration the likelihood that such conditions would be followed and the consequences if they are not.

Conditional exemptions could be used, for example, for the importation of certain GE commodities. A person could petition for an exemption from all permits for shipments of a particular GE commodity grain under the condition that the grain is not grown, but will only be moved for direct use as food, feed, or for processing. The proposed procedure to approve new exemptions would be sufficiently adaptable that it can consider approving exemptions for the shipment of certain GE commodities that would take into account any conditions necessary to make it unlikely to result in the introduction and dissemination of plant pests or noxious weeds.

APHIS considered proposing specific criteria in the regulations that the Agency would use when evaluating potential risks of imported GE commodities which are viable propagules such as grains like corn, wheat, etc. APHIS considered that such a criterion-based system in the regulations might allow APHIS to conduct expedited reviews of imports that met the specified criteria. APHIS considered criteria such as whether the GE plant had undergone a safety review in a foreign country, whether APHIS had granted nonregulated status to something similar, and the likelihood that the commodity could be propagated (seeds, fruit with seeds, nonviable products like flour, etc.).

However, at this time APHIS is not proposing such criteria in the regulation. APHIS does not rule out the possibility of developing such a criterion-based system in the future. We welcome comments from the public on this issue.

We are also proposing regulatory procedures whereby the Administrator may revoke any exemption under this part after it is approved. As proposed, the Administrator may revoke any exemption if the Administrator receives information subsequent to approving the exemption and makes a determination based upon this information that the circumstances have changed such that the exemption is likely to result in the introduction or dissemination of a plant pest or noxious weed. A revocation may not be appealed. However, any person may file a new petition in accordance with § 340.5 regarding the same or similar organisms covered by the exemption if new information relevant to the revocation becomes available.

In addition to this procedure for completely revoking an exemption so it would be unavailable for use by any person, we propose to add a provision in paragraph (e) of the conditional exemptions section, § 340.4, under which the Administrator may revoke the right of an individual person to use an exemption without revoking the exemption for other persons. The Administrator could revoke an individual's right to use an exemption after determining that the person or any agent of the person has failed to comply at any time with any provision of this part.

D. Petitions for Nonregulated Status (§ 340.5)

The current regulations include a procedure by which anyone may petition APHIS to grant "nonregulated status" to a GE organism, which means it would no longer be subject to the regulations in part 340. This nonregulated status is different from that of regulated articles that might be conditionally exempt from the requirement for a permit when moved interstate (following the conditions specified in the regulations).

Published APHIS decisions made under the current regulations have used different ways to express the basic standard "unlikely to pose a plant pest risk" in determining whether to grant nonregulated status to a specific GE organism. In its determinations, APHIS has conveyed the basic standard of "unlikely to pose a plant pest risk" by concluding that the GE organism "poses no more of a plant pest risk than its non-genetically engineered counterpart," "will not pose a plant pest risk"; or that there is "no plant pest risk," or "no direct or indirect plant pest effects." Regardless of the phrases used in its determination of nonregulated status to date, APHIS has applied the same basic evaluation criteria to each determination to conclude that the GE organism is unlikely to pose a plant pest risk and therefore is not subject to the part 340 regulations.

APHIS is proposing revisions to § 340.6 that will clarify the petition procedure, information requirements for petitions, and the standard upon which the Administrator will make a determination that a GE organism is approved for nonregulated status. Under the current regulations, the basic standard for a determination of nonregulated status of a GE organism has been related to plant pest risk. In § 340.6(b)(4) of this proposed rule, we are proposing to apply a similar basic standard derived from the proposed regulatory scope in § 340.0(a), namely, whether the GE organism is unlikely to be a plant pest or noxious weed.

The current regulations also have a provision at § 340.6 to extend a determination of nonregulated status and grant nonregulated status to a GE organism based on the similarity of the GE organism to an antecedent GE organism that has already granted nonregulated status (§ 340.6(e) "Extensions to determinations of nonregulated status"). This provision has been in the APHIS regulations since 1997 and has been used fifteen times to grant nonregulated status to additional GE plants based on similarity to their antecedents. This existing "extension procedure" was designed for APHIS to take into account the previous evaluation conducted by APHIS and thereby afford the potential for expedited evaluations of a petition for extension. The extension procedure has some administrative aspects which are streamlined but in practice the APHIS scientific reviews for extensions are similar to those of the antecedent organism.

Some members of the public have misunderstood the nature of the extension procedure, believing that APHIS has not conducted a thorough scientific review. Some members of the public have misconstrued the term "extension" to conclude that an extension would extend the duration of nonregulated status (nonregulated status is not granted with an expiration date).

For these reasons, APHIS is proposing to eliminate the extension procedure in

the regulation. APHIS sees no advantage to retaining the distinction in the regulations between reviews for antecedents and reviews for subsequent petitions for extensions. Because the proposed revisions for petition for nonregulated status provide a high degree of flexibility, a separate extension procedure is not needed in the regulation. Review of petitions under the proposed regulations will rely on previous evaluations of similar GE organisms when they exist. APHIS foresees that some evaluations for nonregulated status may require less time if previous evaluations have addressed the issues relevant to a new petition for nonregulated status.

In § 340.6 we propose some revisions to the information that the Administrator may require a petitioner to submit in consideration of the particular petition. In the current regulation, the information needs are described largely with respect to evaluating GE plants, but APHIS foresees that other GE organisms may also be suitable candidates. This provision may become more important as new commercial applications of biotechnology emerge and new types of information are needed to properly assess the risks associated with new types of GE organisms. In all of the nonregulated status requests processed to date, the subject organisms and the alterations involved did not present unanticipated or completely novel approaches and APHIS was able to make a determination based on information in the petitions. When needed, APHIS obtained additional information from petitioners, in a consultation process similar to the one proposed.

We are also proposing a regulatory procedure whereby the Administrator may revoke a previous approval of nonregulated status. This is consistent with the existing regulations and policies that the Administrator may place a deregulated GE organism back under the regulations if the Administrator concludes that the GE organism poses a plant pest risk. As proposed, the Administrator may revoke any approval of nonregulated status if the Administrator receives information subsequent to approval that the GE organism is likely to be a plant pest or noxious weed. If the Administrator revokes an approval for nonregulated status, the Administrator may approve for the same GE organism an exemption from the requirement for permit in accordance with § 340.5. The revocation, its effective date, and the reasons for it will be published in the **Federal Register**. A revocation may not be appealed. However, any person may file a new petition in accordance with § 340.5 or § 340.6 regarding the same or similar organisms covered by the revocation if new information relevant to the revocation becomes available.

Treatment of GE Organisms That Have Been Granted Nonregulated Status

Although the APHIS evaluations of GE plants that would be conducted under the proposed regulatory changes will evaluate some additional factors because of consideration of noxious weed risks, APHIS nonetheless considers this proposed revision to be sufficiently consistent with the criteria evaluated in making determinations of nonregulated status to date under the current regulations. For this reason, APHIS is proposing that all previous determinations of nonregulated status made since the early 1990s under the part 340 regulations will be automatically approved for nonregulated status under the revisions proposed here. The history of safe use of these nonregulated GE plants in agriculture in the United States and other countries gives APHIS confidence that it is appropriate to retain nonregulated status under the revised regulations for all those GE plants which have been granted nonregulated status under the existing regulations. Many of these GE plants have been incorporated into plant breeding programs and been used to develop hundreds of crop varieties that have been widely and safely used in agriculture around the world.

We also note that although the addition of the term "noxious weed" is new to the proposed regulation, previous evaluations for determinations of nonregulated status considered the concept of plant pest risk in a broad context that included consideration of potential weediness. The evaluations considered, *inter alia*, whether the unmodified plant was a weed, whether the GE plant was a weed, and whether the interbreeding of the GE plant with sexually compatible plant species would result in offspring that would be weeds. In each case in which APHIS granted nonregulated status to date, APHIS reached the conclusion that in each instance that the potential for weediness was unlikely to occur. In the case of some petitions for nonregulated status in which the GE plants were engineered with sequences derived from plant viruses, APHIS also considered in its reviews whether the genetic modification was unlikely to result in a new plant pest, in this case a plant virus (through mechanisms such as recombination or transencapsidation).

E. Compliance, Enforcement, and Remedial Action (§ 340.7)

1. Ensuring Compliance With Permits and Exemption Activities

In recent years, APHIS has strengthened its program in order to improve permit holders' compliance with the regulations, to augment the approaches used to prevent or remediate potential risks to plant health, and to utilize appropriate enforcement strategies. This proposal provides an opportunity to set forth the compliance and enforcement requirements and the tools and administrative practices APHIS may employ as part of an integrated approach to prevent the introduction or dissemination of plant pests and noxious weeds, and to support overall administration of the program. These matters are addressed in proposed § 340.7, "Compliance, enforcement, and remedial actions." These proposed regulatory changes also reflect certain provisions of the 2008 Farm Bill and align with recommendations of USDA's OIG.

APHIS seeks to clarify that it will use the full range of enforcement authorities and penalties granted under the PPA. As described above, APHIS issues permits with specific conditions or requirements placed upon the responsible person. Proposed § 340.7 clarifies the requirement for compliance with these conditions, as well as the approaches available to APHIS to verify compliance. Such conditions may include requirements for the responsible person to establish and maintain records related to the permit, as well as allowing APHIS to review those records. This section underscores APHIS' ability to conduct inspections and audit records related to the regulated activities.

In this proposed rule, the requirements for record retention are being increased. Records indicating that a GE organism that was imported or moved interstate reached its intended destination must be retained for at least 2 years after completion of importation or interstate movement, and all other records must be retained for at least 5 years after completion of all obligations required under a relevant permit or exemption. APHIS is also proposing changes to the nature of the records that are required, a topic discussed in greater detail in section E of this document, "E. Paperwork Reduction Act." Changes include a requirement to maintain records for activities done under a conditional exemption, as well as contracts and other information related to agreements between the responsible person and all agents that conduct activities subject to this part.

In a previous section of this proposal we discussed the types of records proposed as core permit conditions in § 340.3. We also propose to add certain recordkeeping requirements to § 340.7 that would apply not just to responsible persons exercising permits, but to all responsible persons and their agents engaged in the importation, interstate movement, or release into the environment of any GE organism that is subject to this part, including persons utilizing the conditional exemptions from permits.

In recent years, APHIS has accrued a great deal of experience in enforcing the regulations and investigating possible violations of them. This experience has helped us identify specific types of records that may not be required by the current regulations, but that are necessary for effective enforcement of the proposed regulations.[2] For example, in investigations of field trials we have found that we could not always obtain detailed maps for each planting area used during each season of the trial. This information is important for the efficient enforcement of the regulations. We also found that sometimes records of actual field trial operations over time were not sufficient to confirm that the procedures, equipment, and safeguards APHIS approved for a field trial were actually employed. That is, while existing records could generally confirm plans to use, for example, certain cleaning equipment or procedures at certain intervals, or to conduct plantings on certain dates, the records did not confirm that plans were actually carried out on the approved dates. We also found that records for some field trials did not identify which staff members or contractors were responsible for performing which duties, either during a field test or in the event of an unauthorized release that triggered the field test contingency plan. When responsibilities cannot be linked to specific individuals, it makes it very difficult to investigate possible violations. Another gap in necessary records we discovered through experience was the absence of clear written records of the responsibilities of different organizations, when several different entities were involved in a field trial. During investigations we may need to review not only any written contracts, but also any written agreements among researchers, developers, or other parties that are sharing performance of tasks required by the permit for a field trial.

The proposed regulations would allow APHIS to require these types of records. As APHIS considered the types of records needed to support the regulations it became apparent that regulations could not specify in a "one size fits all" fashion all record requirements that might be needed. Therefore, we propose to add those detailed record requirements of truly general applicability in § 340.3 and § 340.7. However, we also propose in § 340.3 that we would continue to impose any necessary additional record requirements appropriate to each permit situation as individual permit conditions.

Proposed § 340.7 also outlines the possible consequences of failure to comply with the regulations, including denial of future permits; revocation of current permits; destruction, treatment, and removal of GE organisms; issuance of penalties; and a means to settle alleged civil violations prior to the issuance of an administrative complaint.

Under this proposal, every person whose activities are within the scope of the regulations must comply with all the requirements of this part. Moreover, a responsible person can be held liable for the violation of any requirement of this part by any agent working for the responsible person (including persons contracted to conduct or carry out the environmental release on their own or on leased properties).

We propose to address remediation authority and procedures to a greater degree of detail than the current regulations. In proposed §§ 340.7(e) and (g) we explicitly state that the APHIS Administrator has the authority to take remedial actions in the event that an incident requires such actions. We also specify that the APHIS Administrator has the authority to order remedial action by others. These orders could take the form of an Administrative Order, Emergency Action Notification, or similar regulatory instrument. Additional information about these types of orders and related procedures are provided in administrative guidance on the APHIS Web site. The consequence for failure to abide by the orders of the Administrator is also described in proposed § 340.7, linking remediation to enforcement.

Finally, APHIS has clarified in the proposed regulations that in the event of a permit revocation, it may act or order action of the responsible person in the handling of the organisms, articles, or means of conveyances.

2. Low Level Presence of Regulated GE Plants in Seed or Grain

On March 29, 2007, APHIS published a **Federal Register** notice titled "Policy on Responding to the Low-Level Presence of Regulated Genetically Engineered Plant Materials" (72 FR 14649–14651; Docket No. APHIS–2006–0167. This notice described how APHIS responds when low levels of regulated GE plant materials occur in commercial seeds or grain that may be used for food or feed. This issue was also addressed in the DEIS in Issue 7. Both of these documents described how APHIS has addressed these occurrences in the past, and how the Agency intends to address them in the future. We are proposing to amend the current regulations to explicitly incorporate APHIS' low level presence policy.

As described in the DEIS, APHIS proposes to establish criteria under which the occurrence of a low level presence (LLP) of GE plant materials in seeds or grain may not be cause for agency remedial action. APHIS would still retain discretion to order corrective or remedial actions in situations that meet the non-actionable criteria, when the Administrator determines remedial action is needed to make the LLP unlikely to result in the introduction or dissemination of a plant pest or noxious weed. We propose to list criteria and describe possible enforcement actions in the regulations to improve transparency regarding how APHIS would respond to LLP in most instances. APHIS will not predetermine a specific level that is considered non-actionable as far as taking some remedial and/or enforcement action because this determination should always be made case-by-case. These criteria are intended to apply only to APHIS' decision to take or order remedial action in the event that LLP occurs. The proposed criteria are listed within the section describing the Administrator's ability to take or order remedial actions. Regardless of whether APHIS considers the LLP actionable with regard to remediation, any violations of the regulations or permit conditions could still result in any of the compliance and enforcement actions listed in the regulations, including imposing civil penalties.

APHIS is proposing a new provision in the regulations that would reflect the current policy cited above. The provision describes the criteria APHIS will use when determining that a LLP event would be non-actionable with regard to remediation, namely when the criteria support a conclusion that the

[2] Details of investigations that have led APHIS to propose expanded records requirements may be found in the "Lessons Learned" document cited above, and in investigation report documents on the APHIS Web site, e.g., "2007 Report of LibertyLink Rice Incidents" (*http://www.aphis.usda.gov/newsroom/content/2007/10/content/printable/RiceReport10-2007.pdf*) and "Transcript of Technical Briefing on Rice Investigation" (*http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?contentidonly=true&contentid=2007/10/0285.xml*).

LLP is unlikely to result in the introduction or dissemination of a plant pest or noxious weed. Because the criteria are safety-based, they will be used for incidents of low level presence originating domestically (e.g., from field testing) as well as any low level presence that might be detected in import shipments that may contain organisms subject to regulation.

APHIS also considered two additional criteria, which we have not adopted in the proposed rule. First, we considered a criterion that would require that the genetic material be introduced into the plant using a method that has been demonstrated to result in integration of the new sequences into the plant genome, as defined in § 340.1. We did not include this criterion in our proposal because its relevance in the LLP context is unclear. A second criterion considered was that the genetic material engineered into the GE plant does not encode substances with whose function APHIS is unfamiliar. APHIS did not adopt this criterion since it is redundant with the proposed criteria that will be used, i.e., that the function of the introduced genetic sequences is known and that key food safety issues have been addressed.

The DEIS, in Issue 7, Alternative 3, proposed that APHIS would also consider the LLP safety criteria when deciding whether to issue a permit for environmental release, and what type and severity of permit conditions to assign to the release permit. In its evaluation of permit applications, APHIS does plan to refer to the LLP criteria, as described above.

F. Administrative Changes

1. Confidential Business Information

APHIS is proposing a new § 340.8 to provide further guidance on the manner in which confidential business information (CBI) will be addressed in the implementation of these regulations. This change will support the overall administration of the program. The proposed § 340.8 cites the relevance of the Freedom of Information Act (FOIA) and exemptions from releasing information pursuant to FOIA, namely, 5 U.S.C. 552(b)(4), and states that APHIS may exempt from disclosure to the public trade secrets and commercial or financial information obtained from a person that are privileged or confidential. Proposed § 340.8 also states how persons wishing to protect confidential business information should communicate with APHIS in permit applications, petitions, or other submissions to APHIS.

2. Time Frames for APHIS Action on Permit Applications and Petitions

Current regulations specify time frames within which APHIS must take certain actions, such as issuing permits, acknowledging notifications or issuing decisions on petitions to grant nonregulated status. APHIS experience in the last several years has shown that the time required to complete these actions has increased beyond the time frames originally stipulated in the regulations in 1987 (permits) and 1993 (petitions for nonregulated status). As stated in the current regulation, APHIS is obligated to give its reply in the stipulated time, even if required procedures are not yet complete. Therefore, APHIS proposes to include in § 340.2(d) of the regulations a statement that APHIS will generally respond in the time frames indicated. APHIS believes it is important to continue to meet the indicated time frames whenever possible, but the most important thing is to communicate the actual status of reviews and procedures with applicants rather than be obligated to reach a decision in a certain number of days despite the complexities involved with a review. APHIS is particularly seeking comment on this proposed change from persons with experience under the current time frames.

3. Duration Period for Permits

Under the current regulations, notifications for environmental release and interstate movement are valid for one year, and the duration period for a permit issued for an environmental release is not specified. Currently interstate movement permits are only valid for one year from the date of issuance, and a new import permit must be obtained for each imported shipment.

APHIS will continue to retain the flexibility of the permitting procedure to authorize environmental release permits that can be effective for any appropriate time period. In some cases, it may be most efficient to authorize environmental release permits that are valid for more than a single year. In such cases, APHIS can retain adequate oversight by performing periodic inspections and requiring periodic reports. Experience has revealed situations where field tests lasting more than one year are essential. For example, some environmental releases of GE fruit trees may take several years to evaluate the fruit production that often does not begin for several years after planting.

In order to provide greater flexibility and efficiency, APHIS is also proposing to eliminate the current restrictions in the regulation on the duration of permits for interstate movement and importation. The proposed regulations will remove the requirements that interstate movement permits are only valid for one year from the date of issuance, and that importation permits must be obtained for each individual importation. These changes should give APHIS the flexibility to issue these permits with suitable durations to meet the individual circumstances.

G. Definitions and Miscellaneous Changes

APHIS proposes to change certain definitions in § 340.1 of the regulations, to add certain new definitions, and to remove definitions for terms that are defined in the PPA or that no longer appear in the regulations.

Revised Definitions

APHIS proposes to change the definitions of the following terms in § 340.1:

Release into the environment would read "Dispersal beyond the constraints of a contained facility or secure shipment. Synonymous with the term environmental release."

Secure shipment is a new term defined below. By adding reference to secure shipment in this definition, we clarify the distinction between environmental release and shipments for importation and interstate movement; any such movements which are not done by secure shipment constitute an environmental release.

Responsible person would read "The person who has control and will maintain control over a GE organism during its importation, interstate movement, or release into the environment and assures compliance with all conditions contained in any applicable permit or exemption as well as other requirements in this part. A responsible person shall be at least 18 years of age and be a legal resident of the United States or designate an agent who is at least 18 years of age and a legal resident of the United States." The change from the former definition is the addition of "at least 18 years of age," added to prevent possible enforcement difficulties.

New Definitions

APHIS proposes to add definitions of the following new terms:

Confidential business information, CBI would read "Information such as trade secrets or commercial or financial information that may be exempt from disclosure under Exemption 4 of the Freedom of Information Act (FOIA),

because disclosure could reasonably be expected to cause substantial competitive harm. USDA regulations on how the agency will handle CBI and how to determine what information may be exempt from disclosure under FOIA (5 U.S.C. 552) are found at 7 CFR § 1.12." We propose to add this definition because APHIS has often been asked to clarify what is and is not CBI, and how it is handled. The definition describes typical types of CBI, and the language in proposed § 340.8 describes how persons submitting documents to APHIS can request that identified information be treated as CBI. There is also additional guidance on CBI contained in administrative guidance on the APHIS Web site regarding document preparation for part 340 requests. However, it is important to realize that in actual situations where someone submits a FOIA request for particular information, the APHIS FOIA Officer makes the ultimate determination as to whether particular information shall be released, in accordance with the standards of FOIA, Executive Order 12600, and 7 CFR 1.12.

Contingency plan would read "A written plan stating how the responsible person will respond in the event of the unauthorized environmental release of GE organisms." We propose to define this new term to describe a document mentioned in both the permit application information requirements section (§ 340.2(c)) and the permit conditions section (§ 340.3).

Exempt, exempted, exemption would read "A determination by the Administrator that the importation, interstate movement, and/or release into the environment of an organism or class of organisms described in § 340.0(a) is not subject to the requirement to have a permit under this part. An exemption from one type of permit (e.g., interstate movement) does not remove remaining obligations to obtain other permits under this part." We propose to add this definition for the term *exemption* to refer to situations where a regulated movement is exempt from the requirement for a permit. The proposed definition is based on language in Sec. 411(b)(1) of the PPA (7 U.S.C. 7711(c)), titled "Exception to permit requirement," which authorizes the Secretary to issue regulations to allow the movement of specified plant pests without further restriction if the Secretary finds that a permit is not necessary.

Noxious weed would read "Any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment." This is the definition for noxious weed found in the PPA.

Recipient organism would read "The organism that will receive the genetic material from a donor organism in the process of genetic engineering (once the organism is engineered it is referred to as the genetically engineered (GE) organism)." This definition is needed to properly distinguish organisms and their traits in comparisons of GE organisms to the same organisms prior to transformation.

State or tribal regulatory official would read "State or tribal official with responsibilities for plant health, or any other duly designated State or tribal official, in the State or on the tribal lands where the importation, interstate movement, or release into the environment is to take place." This term is used in reference to consultations with States and tribes under the regulations.

Secure shipment would read "Shipment in a container or a means of conveyance of sufficient strength and integrity to withstand leakage of contents, shocks, pressure changes, and other conditions incident to ordinary handling in transportation."

We propose to add the following two definitions to make it clear that, when the Administrator authorizes it, a signature required under the regulations may be an electronic signature and a written document required under the regulations (e.g., a permit application) may be an electronic document.

Signature, signed would read "The discrete, verifiable symbol of an individual which, when affixed to a writing with the knowledge and consent of the individual, indicates a present intention to authenticate the writing. This includes electronic signatures when authorized by the Administrator."

Write, writing, written would read "Any document or communication required by this part to be in writing may also be provided by electronic communication when authorized by the Administrator."

Deletion of Definitions

We propose to remove the following definitions from the regulations: *courtesy permit, expression vector, introduce or introduction, regulated article, stably integrated, vector or vector agent,* and *well-characterized and contains only non-coding regulatory regions.*

These definitions would be removed because the terms would no longer be used in the regulations. We propose to eliminate the term *regulated article* partly because the use of the term "article" in current part 340 is not consistent with usage in the PPA, which uses the term article to mean "any material or tangible object that could harbor plant pests or noxious weeds"—that is, things like packing materials, shipping containers, commodities, etc.—and not a plant pest or noxious weed itself. Under the current regulation, however, *regulated article* refers exclusively to certain GE organisms. Furthermore, under both the PPA and part 340, "articles" are not regulated, but rather their importation, interstate movement or environmental release is regulated. For these reasons, the term "regulated article" in the current regulations is both inconsistent with the terminology of the PPA and difficult for the public to comprehend.

We also propose to remove the definition for introduction. APHIS currently uses the term in part 340 to denote certain kinds of activities that fall within the scope of the regulation, namely importation, interstate movement, and release into the environment. The PPA, however, does not specifically define the term introduction. Therefore, to avoid confusion, instead of using the term introduction to define the different types of regulated activities, APHIS will instead refer to these specific activities themselves in the regulations, namely, the importation, interstate movement and release into the environment.

Miscellaneous Changes

We also propose to make minor miscellaneous changes to the regulations to improve their clarity and remove redundancies. For example, in addition to adding the definition for CBI discussed above, we are consolidating requirements concerning CBI, formerly contained in several sections of the regulations, into proposed § 340.8.

IV. Required Analyses

A. National Environmental Policy Act

On January 23, 2004 (69 FR 3271), APHIS published a notice of intent to prepare a draft environmental impact statement (DEIS) in accordance with the National Environmental Policy Act in connection with the regulations at 7 CFR part 340 and potential changes to those regulations. This notice identified potential issues and alternatives to be studied and requested public comment to shape the scope of the DEIS.

On July 17, 2007, APHIS published the DEIS evaluating regulatory alternatives under consideration and solicited public comment on the DEIS

(72 FR 39021–39025). The Environmental Protection Agency published a separate notice on July 13, 2007, soliciting public comment on the DEIS (72 FR 38576–38577). The notices sought comments on the quality of our analysis of potential environmental effects of the alternatives under consideration, and also sought views on how each alternative would affect areas such as the overall effectiveness of our biotechnology program, its operational efficiency, industry compliance issues, or other issues that would be associated with the implementation of an alternative.

The major elements of this proposed rule were accurately described in the alternatives contained in the DEIS and their potential environmental effects were analyzed in the DEIS. Table 4 below provides a comparison between the proposed changes to part 340 and the DEIS. We received numerous comments on the DEIS, which will be discussed fully when we publish a final environmental impact statement (FEIS). The DEIS and the comments on it were used by APHIS to inform decision makers and aid the design of this proposal. Information from the DEIS comments, along with information from many other sources, including certain provisions of the 2008 Farm Bill and recommendations from USDA's OIG, was used to inform the drafters of this proposed rule about the issues perceived to be involved in and addressed by the rulemaking. We will respond to all DEIS comments in detail in the FEIS since the agency action (revising the regulations in part 340) is still subject to change based on comments and information received on this proposed rule, and thus we cannot provide definitive and final comment responses until we issue the FEIS and the final rule.

Consideration of the DEIS comments led APHIS to refine and reorganize some of the regulatory alternatives it considered. Therefore, the presentation and discussion of the alternatives proposed in this proposal do not exactly match those described in the DEIS. The differences are primarily a matter of reorganizing and realigning some material and their corresponding regulatory alternatives, using more descriptive terms in some criteria listed in the alternatives, and choosing between regulatory alternatives that fall within the analysis of the DEIS. Accordingly, the DEIS is still consistent and applicable as an analysis of the potential environmental effects of the proposed action. However, we are interested in receiving comments on whether any of the proposed regulatory alternatives in this document do not appear to have been adequately addressed within the DEIS.

TABLE 4—SUMMARY OF PROPOSED CHANGES TO THE REGULATIONS AND RELATIONSHIP TO DEIS

Summary of proposed substantive changes to the regulation	DEIS issue	DEIS alternative
Redescription of which GE organisms are subject to the regulations.	1	2 (DEIS preferred alternative) or 3.
Deletion of the list of plant pest taxa in the regulations and the petition procedure to amend the list.		
Clarification that APHIS has the authority to regulate nonliving materials through permit conditions in cases where such materials may pose a risk as a noxious weed.	5	2 (DEIS preferred alternative).
Revision of the application information requirements and permit conditions for all permit types.		
Elimination of the current notification procedure for importation, interstate movement, and release into the environment of certain types of GE plants (permitting procedure will be used instead).	2	4 (DEIS preferred alternative).
Revision of the permitting system for environmental releases:	2	4 (DEIS preferred alternative).
• Subdivision into 5 categories of permits for environmental releases (4 for GE plants, 1 for other GE organisms).	4	2 (DEIS preferred alternative).
• Continue strict permit conditions for environmental releases of GE plants engineered to produce compounds intended for pharmaceutical or industrial uses.	6	1 (No action alternative).
Continued use of permits with appropriate conditions for single or multiple year releases.		
Creation of new administrative procedures in permitting: (1) The explicit agreement of the responsible person to comply with regulatory requirements of the permit, (2) amendment of existing permit conditions, (3) transfer of permits to a different responsible person, and (4) revocation of a permit.		
Elimination of the prescribed shipping container provisions in favor of a performance based approach specified as permit conditions for importation and interstate movement.	10	2 (DEIS preferred alternative).
Revision of the existing conditional exemptions for interstate movement such that the shipping standard is part of the exemption. Addition of a recordkeeping requirement for persons using the existing conditional exemptions.		
Elimination of the option for APHIS to issue courtesy permits for importation, interstate movement, and environmental release of GE organisms which are not subject to the regulation.		
Creation of a petition procedure for the Administrator to approve additional conditional exemptions from the requirement for a permit. This also includes a description of administrative steps if Administrator revokes an exemption, amends the conditions of an exemption, or prohibits a person from using a conditional exemption.	3 8	2 (DEIS preferred alternative). 1 (DEIS No Action alternative).
Clarification and revision of the existing petition procedure for determining nonregulated status, including elimination of the procedure to extend a previous determination of nonregulated status, and a description of the administrative steps if Administrator revokes nonregulated status.		
Clarification of the actions the Administrator may take related to compliance, enforcement, and remediation.		
Clarification of APHIS approach to the low level presence of regulated GE plants in seed or grain.	7	3 (DEIS preferred alternative).
Definition of Confidential Business Information (CBI) and description of administrative practices for CBI.		

We received approximately 23,000 comments on the DEIS, of which more than 22,000 were variations of several form letters. There were also several lengthy and detailed evaluations of environmental, scientific, legal, cultural, and economic issues raised by the DEIS. APHIS took all comments related to regulatory changes under consideration as we developed the content of this proposed rule, and altered a number of preliminary ideas for the proposal based on comments. We will fully summarize and address the comments received on the DEIS in a Final Environmental Impact Statement to be prepared in conjunction with the publication of a final rule. In addition to specific DEIS issues that were discussed above in the Preamble, the following section summarizes and discusses those comments on the DEIS that were most directly related to the regulatory alternatives discussed in this proposed rule and the ways in which these comments affected development of the proposal.

Many DEIS commenters addressed how the regulations should use the PPA authorities regarding noxious weeds, plant pests, and biological control organisms. Most comments on the DEIS that addressed this issue stated that APHIS should expand the scope of its regulatory program beyond plant pests to include both noxious weeds and certain biological control organisms, consistent with all of the regulatory authorities of the PPA. The following opinions were expressed regarding PPA authority regarding noxious weeds and the meaning of the PPA definition of noxious weed.

Very few commenters suggested that APHIS biotechnology regulations should implement the PPA's noxious weed definition in its broadest possible sense. One commenter suggested that APHIS broadly interpret the phrase "other interests of agriculture," in the PPA definition of noxious weed such that APHIS would consider a plant to be a noxious weed if it poses solely economic harm, i.e., in the absence of physical harm. As explained previously in this proposal, such an interpretation is not consistent with the PPA, nor with the manner in which APHIS–PPQ has implemented the noxious weed program pursuant to the PPA. Many commenters suggested that APHIS needed clear regulations or policies to describe how it will be evaluating whether GE plants pose threats as noxious weeds. APHIS agrees and has framed this proposal to clarify the issue for the public.

Some commenters stated that APHIS should acknowledge limits to its consideration of potential damage to public health in APHIS regulations, and the noxious weed definition should not be interpreted so broadly as to provide APHIS with the legal responsibility or authority to determine the food safety of GE crops or to prevent GE crops from entering the food supply. The commenters stated that Congress clearly intended the FDA to be responsible in this area.

We agree, and this proposal acknowledges FDA authority in the food safety area. However, it is important that the regulatory procedures in each agency dovetail and support each other where agency mission areas come in contact. This proposal recognizes this need for mutual agency support. When a permit for environmental release, importation, or interstate movement of a new GE organism is submitted to APHIS, we would evaluate whether there are any signs that the environmental release, importation, or interstate movement of the organism could present risks to the public health. If APHIS is concerned that there may be food safety risks associated with the GE organism, we would contact FDA. The decision on whether or how to regulate food and feed from the GE organism to address food and feed safety risks would then be FDA's. On the other hand, it is also likely that existing food safety evaluations will prove to be useful and relevant to APHIS evaluations of a GE organism. Food safety concerns are one of several factors APHIS would take into account when considering, for example, what types of permit conditions are needed for the environmental release of a GE organism, or whether activities associated with the organism should qualify for an exemption from the permit requirement.

Several commenters stated that under the current regulations APHIS has always considered noxious weed risk, or at least "weediness." We agree that in practice, when APHIS assesses a GE plant it has always evaluated the potential weediness of the GE plant in relation to its plant pest potential. In the context of the PPA, "weediness" is more properly a noxious weed risk characteristic than a plant pest one, and the proposed revision of the regulations will more clearly align the regulations with the plant pest and noxious weed risk pursuant to the PPA. Current APHIS regulations and guidance directly address the importance of including weediness when evaluating risks associated with GE organisms. For example, when the petition procedure to grant nonregulated status was added to part 340 in 1993, the traits APHIS listed for evaluation explicitly included "weediness of the regulated article" (see current § 340.6(c)(4)).

Several DEIS commenters addressed what characteristics should trigger regulation of a GE organism, or put another way, how to set the scope of organisms subject to regulation. In the DEIS, APHIS explored many options including continuing to make its decisions primarily based upon the transformation event (also sometimes referred to as the individual transformed line, transgenic line or GE line). Some members of the public refer to this as an event-by-event approach. It is sometimes contrasted with a "trait-based" approach that focuses more on the resulting trait or phenotype of the GE organism. In a trait-based approach, a regulatory decision for an organism engineered for one phenotype would apply equally to other GE organisms if they had the same phenotype or trait, regardless of whether they were engineered with the same genes. APHIS invited comment on the relative merits of the event-by-event approach and the trait-based approach. The current regulations do not limit APHIS to one approach or the other. Many readers equated "event-by-event" with a "process-based" system and likewise equated "trait-based" regulation with a "product-based" system. Thus many comments focused on the relative merits of a product-based system versus a process-based system.

Some suggested that the trigger be "process-based", i.e., the process of modifying the organism by recombinant DNA techniques would be the determinant. Others suggested the trigger be "product-based", i.e., the nature of the resulting product (organism) would be the determinant for whether the organism would be subject to the regulation. Many of the comments were not actually related to the basis for the trigger, but rather to the focus of the risk assessment, with most stating that the risk assessments should be based on the biology of the organism (product-based), not the technique by which it was made (process-based). One commenter believes that the process of genetic engineering is a useful trigger, but once regulated, the characteristics of the GE organism should dominate APHIS considerations of safety.

Those supporting a process-based approach for identifying which organisms should be subject to regulation stated that each GE organism can have unintended as well as intended changes, and that these unintended changes to the organism would require that each individual resulting from genetic engineering must be assessed on a case-by-case basis.

Some commenters also suggested that this approach of APHIS assessment of each individual GE organism better protects the environment and human health than an approach that focuses primarily on the trait(s) of the GE organism.

Some commenters against process-based approach stated that this approach is illogical, on the one hand, to regulate a plant species with no known risks only because GE techniques were used to modify it, whereas on the other hand the same plant species modified by other techniques faces no additional regulatory requirements from APHIS.

Those supporting a product-based regulatory approach stated that it would be aligned with the preponderance of scientific opinion on the issue, that the characteristics of the organism should take precedence over the technique of genetic modification in the APHIS assessment of the organism. APHIS agrees that any evaluation of risk should be based on the biology of the product.

Several commenters suggested that the definition of *regulated article* would have to be reexamined and possibly redefined to reflect changes in the PPA. Commenters also stated that the term *regulated article* was problematic whether linked to specific taxa in § 340.2, under the current regulations, or linked to plants produced by particular technologies. These commenters emphasized that actions under the regulations usually amount to an investigation of whether an article (GE organism) needs to be regulated, and that predefining the subject of the investigation as a regulated article strongly implies that a decision has been made to require some regulatory oversight.

The proposed elimination of the term "regulated article" would facilitate a clearer understanding that it is not the GE organism that is regulated, but rather the importation, interstate movement, or release into the environment of the GE organism.

APHIS determined that eliminating "introduction" as a defined term would facilitate clearer understanding that the activities subject to the regulations are in fact importation, interstate movement, and release into the environment.

In the DEIS, APHIS discussed the need to regulate nonliving products of GE organisms. The preferred alternative was to have a procedure to regulate non-viable material only in certain rare circumstances when it might pose a risk. Most of the DEIS comments addressing this issue agreed that APHIS should regulate nonviable GE plant material only in certain circumstances, based on the risks posed. The few comments that provided greater detail identified toxicity risks and possible persistence in the environment of toxic nonviable plant parts or debris as the most significant risk associated with nonliving GE products. A few commenters also stated that adding a clear definition of "nonliving" or "nonviable" would aid the regulations.

APHIS has responded to these comments in this proposal by not usually regulating nonliving GE products, and by providing that when any control is needed over such a product that is associated with a living GE organism which is covered by a permit, due to toxicity or other risks, such controls would be included as permit conditions in permits issued for the associated living GE organism. We propose to provide for this by adding the following sentence to paragraph (b) of § 340.3, *Permit conditions:* "The Administrator may also assign permit conditions addressing nonliving materials associated with or derived from GE plants when such conditions are needed to make it unlikely that the nonliving materials would pose a noxious weed risk."

We received one DEIS comment directly addressing the issuance of courtesy permits. This comment supported retaining use of courtesy permits, and stated that courtesy permits facilitate the importation of GE *Drosophila melanogaster* strains by the research community and also ease the workload for APHIS. The continued issuance of courtesy permits diverts Agency resources unnecessarily from organisms that are within the scope of the regulations. We intend to help develop informational materials for the research community and other agencies that are aware of courtesy permits to clarify that such permits are not required, and to explain this to any persons who contact us requesting courtesy permits in the future.

Several DEIS comments addressed the notification procedure and supported eliminating it. Some comments suggested that the types of organisms formerly eligible for the notification process should instead be handled through a two-tiered permitting process, with experimental permits for field trials and commercial permits for GE crops that are to be sold in commerce. Other comments suggested that while some organisms might require permits with minimal conditions rather than notifications, others with even lower risks could be exempted from permit requirements. These latter comments also generally suggested that some of the criteria in the current regulations used to determine eligibility for the notification process could be preserved in the new regulations as criteria to identify organisms that should be exempted from the requirement for a permit. One commenter stated that since the current "notification" process involves acknowledgment by APHIS and conditions as well as notification, changing to a system of low risk permits would be a *de facto* acknowledgment of the current process. To address these issues, APHIS is proposing to eliminate notifications and to handle regulated GE organisms that previously would have been eligible for notifications through a permitting procedure.

We received a few comments on the DEIS generally related to procedures for reviewing permit applications. Comments stated that the role of States in reviewing or approving permit applications for GE crops has been very important and useful under the current regulations, and should continue in future regulations. Comments also stated the importance of scientific integrity in the review process, and emphasized the importance of coordinating with other agencies (particularly FDA and EPA review) when issues within their mission area arise during APHIS review of applications.

The proposed changes to the permit application procedure address these concerns. States would have a continuing role in application review that is very similar to their existing role, and we have been increasing interactions with the relevant tribal authorities in recent years.

Several comments were peripherally related to the DEIS issue of whether APHIS should establish standard or general permit conditions or what they should require. These comments emphasized that the purpose of permit conditions is to control risks not otherwise controlled, and that permit conditions must be developed in response to careful consideration of the risks presented by the particular permitted activity. One comment stated that APHIS should not require permit conditions that have the primary purpose of preventing crops from entering the food supply, because APHIS does not have the legal authority or scientific expertise to set them.

We have taken these views into account in designing this proposed rule. Proposed § 340.3 describes the core list of general conditions that APHIS would impose on all permits as well as additional conditions for specific types of permits. APHIS is also making it clear that APHIS may also add other specific

conditions to a permit upon its issuance. Conditions are specific practices or requirements that an applicant must follow upon issuance of a permit. Conditions are added as a consequence of the APHIS evaluation in order to make it unlikely that actions under the permit would result in the introduction or dissemination of a plant pest or noxious weed.

Several DEIS comments stressed that APHIS needs to do more to ensure that the permit conditions it sets are actually followed and enforced. The changes to permit procedures proposed for § 340.2 contribute to that goal by obtaining written agreement from the responsible person that he or she, and all of their agents, must comply with all of the permit conditions before issuance of the permit.

Almost all DEIS comments on containers or marking and identity for regulated articles supported performance standards for containers. Most of these commenters made the point that performance criteria are generally more adaptable and efficient than prescriptive criteria. Some stated that shipping research organisms interstate in enclosed containers is a low-risk activity that is very unlikely to result in release, establishment or harm.

Some commenters stated that the type of container indicated by performance standards must be appropriate to the level of risk in the tiered permit system for the shipped GE organism. One commenter requested that APHIS make its container standards consistent with the International Air Transporters Association (IATA) requirements for shipping.

The way this proposed rule deals with container standards is consistent with the above DEIS comments.

Most of the commenters addressing tiered or categorized permit systems supported APHIS establishing a tiered permitting system for plants based on criteria that included risk and other GE organism characteristics. However, commenters also stressed that risk categories should be based on a trait by species approach, not on the basis of individual transformed plant line (referred to as "event-by-event" in some of the comments). Some commenters advised against using limited broad based categories that include many different species with different biologies and different risk factors. Several stated the importance of evaluating permit applications on a case-by-case basis, to avoid the risk that categorizing permit types could result in approval of risky releases that were inadvertently seen as "routine categories."

Several commenters stated that a tiered permitting system should be flexible and allow consideration of any factors that seem relevant, or allow reclassification of a GE plant from one tier to another based on additional characterization information and agency familiarity with the GE plant. Some commenters opposed the development of a tiered risk-based permitting system because each transformation event can have unintended effects that must be assessed on a case-by-case basis, rather than through predefined categories. We have addressed these views in this proposed rule by changing the permit tier system described in the DEIS to a proposed permit application categorization system that is more flexible than the system described in the DEIS.

In the DEIS, APHIS considered whether to continue to issue environmental release permits for GE plants engineered to produce pharmaceutical and industrial compounds if the GE plant species is the same as, or sexually compatible with, a species commonly used for food or feed. APHIS concludes that the permitting procedure with its stringent permit conditions can continue to effectively minimize the risks that may be associated with the environmental release of such GE plants. APHIS will continue to impose appropriate permit conditions that take into account the issues related to the public safety of proteins or other substances that these plants have been engineered to produce.

Numerous commenters supported banning the outdoor production of pharmaceuticals and industrial substances in food and feed crops. Some stated that food crops should not be used for the production of pharmaceuticals and industrial substances.

Some commenters stated that GE plants used for the production of pharmaceuticals and industrial substances should be evaluated by criteria that are different from those used to evaluate crops intended for food. Other commenters stated that if such GE industrial plants were made from food crop species, or could spread genes to food crop species, they should be evaluated based on food safety risk, not the industrial product's function, and approved only if they pose no food safety risks. However, with regard to evaluating food safety, several commenters also stated that FDA should be the agency evaluating these risks.

We have not seen evidence suggesting that these types of organisms present unique or uncontrollable risks, or risks higher than those that may be associated with many other uses for GE plants. Our approach in this proposed rule addresses the other concerns cited by DEIS commenters.

Many commenters were concerned that the outdoor cultivation of GE plants producing pharmaceutical and industrial compounds could be a source of gene flow to nearby non-GE plants or result in the co-mingling of grain with related crop species intended for food or feed. Risks associated with this scenario may be abated by either of two means: (1) Preventing such gene flow or co-mingling from occurring, or (2) establishing that if such gene flow or co-mingling to other plants does occur, it does not present an unacceptable risk of introducing or disseminating a noxious weed.

Such gene flow can be minimized or substantially prevented through permit conditions developed for environmental releases of GE pharmaceutical or industrial plants. In many cases the genetic and phenotypic characteristics of the organism also serves to discourage survivability of the plant away from the intended site as well as gene flow to other plants. During the review prior to permit issuance, APHIS would also always consider the effects if the GE plant were likely to spread widely, or if large-scale gene flow to other plants occurred. A permit for an environmental release would not be approved if APHIS concluded there was a likelihood of such events causing any of the types of harm as described in the noxious weed definition.

One DEIS comment on the issue of multiple-year permits stated that compliance agreements should be used instead of actual multiple-year permits. Another suggested that multiple-year permits should be limited to trait/crop combinations not intended for feed or food use. In contrast, another comment stated that APHIS should consider allowing multi-year permits for any product, not just GE pharmaceutical or industrial plants.

Several commenters stated a risk-based opposition to multi-year permits and stated that crops engineered to produce pharmaceuticals or industrial compounds should always be regulated under an annually-reviewed permit system.

This proposed rule addresses the risk-based concerns cited by commenters in the proposed processes for issuing permits and granting exemptions, discussed elsewhere in this document. We propose to allow multi-year permits for any type of regulated activity, when we determine that appropriate risk-related conditions can be prescribed for those activities. We have not seen any

convincing evidence, in DEIS comments or elsewhere, that limiting use of multi-year permits to certain types of organisms would reduce risk or otherwise serve the purpose of the regulations.

Of the approximately 67 comments received by APHIS on the interstate movement exemptions discussion in the DEIS, 30 comments appear to support APHIS' preferred Alternative 2, under which APHIS would exempt from permit requirements for interstate movement a class of GE plants or organisms that are well-studied and present little or no environmental risk, as is currently done for *Arabidopsis*. However, many of these commenters suggested that APHIS choose an approach that combined this with one or more of the other Alternatives. Several commenters stated that the regulations should provide a procedure for APHIS to consider additional exemptions from interstate movement restrictions on a case-by-case basis.

APHIS has concluded that the most appropriate proposal for the regulations at this time is to provide a clear and adaptable procedure whereby it would use a case-by-case approach to consider the merits of new exemptions from the requirement for a permit. The procedure, described in proposed § 340.5, would allow for a transparent procedure in which APHIS would evaluate the proposed exemption, and the public would have an opportunity to review APHIS' evaluation and provide comments prior to APHIS decisions on individual cases. The proposed procedure should provide the benefit of transparency and scientific rigor while affording a more streamlined and cost-efficient procedure that would not require formal amendment of the regulations when each new exemption is approved.

Several DEIS comments addressed what criteria in the regulations the Agency could use to determine the level of risk assessment applied to imported GE commodities which are viable propagules. They fell into two general groups. Both groups stated that any expedited review or exemption for GE commodity imports needed to be granted based on a review of risk and a determination that the importation presented no significant risks. Beyond that, one group emphasized that commodity imports were in general inherently safe, and such an expedited system would be appropriate and would also greatly facilitate international trade. The other group was skeptical about inherent safety of GE commodities and suggested that exemptions should only be offered when there are procedures ensuring that the commodities are made non-viable or safeguards are in place to ensure that propagation will not occur. Some comments in this group also stated that such exemptions should not be granted for a GE commodity from any country until APHIS has confidence that the country has robust regulatory guidelines and assessment standards with strong, reliable science and trustworthy regulatory oversight, equivalent in effectiveness to the U.S. system.

One comment included a general statement that it was important that a petitioner for deregulation or exemption should work closely with APHIS to develop and evaluate the management plan under which the subject GE organism would be grown if deregulated or exempted. APHIS agrees that its regulatory approach should include working closely with petitioners on their proposals for exemption, especially if management plans are part of the requisite conditions. APHIS would retain some degree of oversight and could restrict movements of a GE organism such that the exemption and its conditions are unlikely to result in the introduction or dissemination of a plant pest or noxious weed. The proposed procedure to approve additional conditional exemptions is sufficiently adaptable even when the exemption is for all forms of movement (i.e., importation, interstate movement, and environmental release).

Very few DEIS comments directly addressed enforcement and compliance. A few comments stated that APHIS regulatory oversight and enforcement of its regulations in the past have been insufficient and have provided inadequate containment of GE crops. This proposed rule would strengthen enforcement and compliance and enhance the effectiveness of the regulations.

Comments on the discussion in the DEIS of low level presence ranged from suggestions that APHIS should completely prevent such incidents by banning all outdoor growth of GE plants to suggestions that LLP is a minor problem needing only minimal controls, and does not warrant an increased regulatory burden to control a minor risk. Some commenters stated that the preferred alternative in the DEIS accepted too high a level of risk. These commenters generally preferred DEIS alternative 4, which would impose very strict permit conditions on all environmental releases to reduce the likelihood of LLP events. Most commenters agreed that APHIS should adopt an LLP policy that recognizes the wide variety of risk levels associated with such incidents, and that beyond applying general criteria APHIS should investigate each unauthorized release individually and determine actions based on the facts surrounding each incident. Some commenters stated that any LLP policy should clearly state that even if an incident was found to be non-actionable (i.e., not requiring remedial action), persons involved would still be subject to enforcement actions such as civil penalties if violations of the regulations occurred.

APHIS has considered all these views in the development of this proposed rule and has attempted to find a reasonable balance. It is not warranted, or practical, to implement a "zero tolerance" LLP policy. Instead, we propose a policy that each LLP incident would be individually investigated, and APHIS would then make a decision on whether, or what kind of, remedial action is needed. In making this determination APHIS would use established criteria to rate the risks involved in the LLP incident. However, these criteria would not fully determine the APHIS response. In addition to considering the criteria, APHIS would evaluate any other relevant information regarding the LLP incident and order remedial action if it appears necessary.

Also, we propose to clearly state that regardless of whether APHIS considers the LLP actionable with regard to remediation, any violations of the regulations or permit conditions can still result in compliance and enforcement actions for failure to comply with the regulations.

One DEIS comment directly addressed timelines for APHIS to perform permit- and petition-related activities and urged APHIS to continue to define specific timelines for regulatory reviews to allow for a predictable regulatory review system. The comment stated that time frames are especially critical for field trial permitting activities since planting occurs during a narrow window each year and a delay of a month or two in a regulatory decision can result in a year delay due to the inability to timely plant a field trial.

We understand the concerns, and have decided to keep the time frames in the text of the regulations. However, as discussed above, APHIS will view them as performance goals and will generally respond in the time frames indicated, rather than be obligated to respond at those times. In recent years, there has been an increase in the time required for APHIS review due to the increasing complexity of issues related to environmental effects, new traits, and unfamiliar species. In addition to

retaining general time frames in the regulations, APHIS intends to discuss time frames with each applicant early in the application process, and to the extent possible give the applicant reliable time estimates based on the nature and complexity of the particular application and current APHIS activities and resources that are expected to affect the application review.

B. Executive Order 12866 and Regulatory Flexibility Act

This proposed rule has been reviewed under Executive Order 12866. The rule has been determined to be significant for the purposes of Executive Order 12866 and, therefore, has been reviewed by the Office of Management and Budget.

We have prepared an economic analysis for this proposed rule, which is summarized below. Copies of the full economic analysis are available by contacting the person listed under **FOR FURTHER INFORMATION CONTACT** or on the Regulations.gov Web site (see **ADDRESSES** above for instructions for accessing Regulations.gov). The analysis provides a cost-benefit analysis, as required by Executive Order 12866, and an analysis of the potential economic effects of this final rule on small entities, as required by the Regulatory Flexibility Act.

Background

The adoption of genetically engineered (GE) crops by farmers worldwide has become increasingly widespread. The United States, Argentina, Brazil, Canada, and China are the major GE crop adopters. In 2008, 92 percent of soybean, 80 percent of corn, and 86 percent of cotton acreages planted in the United States were genetically engineered (USDA NASS, 2008). In addition to the major field crops, GE varieties of papaya, yellow squash, and zucchini were available for commercial production in 2008.

Worldwide plantings of transgenic crops grew by 12 percent in 2007, reaching 282.4 million acres in 23 countries growing biotech crops in 2007, including 12 developing countries. Over the next decade, use of these "first-generation" GE crops, which carry traits such as insect resistance and herbicide tolerance, should continue to grow while a second generation of crops promises new applications and traits such as improved drought tolerance, biofuel-related enhancements, and quality and nutritional traits.[3]

[3] Global Status of Commercialized Biotech/GM Crops, ISAAA Briefs 37–2007, 35–2006, The International Service for the Acquisition of Agri-Biotech Applications, Cornell University.

The benefits associated with the use of some GE crops already in production include higher yields, lower pesticide costs, and overall savings in management time. There are also environmental benefits from reduced pesticide use. Attempts have been made to quantify the benefits that have occurred as a result of the adoption of GE crops and, according to a recent survey, farm-level net economic benefits worldwide from the adoption of GE crops were estimated to be $7 billion in 2006 (Brookes and Barfoot 2008). Total net benefits, 1996–2006, were estimated to be $34 billion. Of this total estimated net welfare gains, the United States experienced the largest benefit, with $15.8 billion; followed by Argentina, $6.6 billion; China, $5.8 billion; and Brazil, $1.9 billion (Brookes and Barfoot 2008). U.S. farmers' welfare gains from the adoption of biotechnology ranged from 29 to 42 percent of total net welfare gains (Price *et al.* 2005; Falck-Zepeda, Traxler, and Nelson 2000).

The high rate of GE crop adoption by farmers has been driven by an increase in consumption of product developed with the use of GE techniques. However, studies that quantify consumers' benefits from the use of biotechnology are limited, as most studies tend to focus on the direct adopters of biotechnology, i.e., the producers. Price *et al.* (2006) found consumers do benefit from the adoption of Bt cotton.

Overall, consumers' gains from the adoption of various GE crops have been estimated to range from 4 to 17 percent of total net welfare gains (Price *et al.* 2005; Falck-Zepeda, Traxler, and Nelson 2000).

Crop producers and consumers are not the only beneficiaries of recent advances in biotechnology. The providers of biotechnology have also benefited from the increased adoption of GE products. Intellectual property right laws have offered incentives for the private sector to invest in research and development of GE products, and as a result, plant breeding expenditures have largely shifted from the public to the private sector (Fuglie 2006). As private research spending has increased, so has the number of firms engaged in this type of research. However, consolidation and mergers during the 1990's resulted in an industry dominated by large companies. Currently, 80 percent of biotech traits that have been approved are owned or co-owned by four firms (Bayer Crop Science, DuPont, Monsanto, and Syngenta) or their subsidiaries (Kalaitzandonakes, Alston, and Bradford 2007).

With regard to the beneficial effects for the environment of GE plants in commercial production, their production has resulted since 1996 in decreases in the use of pesticides by 286 million kg and in the use of herbicides by 51 million kg (Brookes and Barfoot 2008). These declines represent 7.9 percent reductions. In terms of greenhouse gases, one study estimated cultivation using no-tillage systems associated with GE crops modified for herbicide tolerance to reduce fuel use by 32.52 liters/ha (89 percent) compared to conventional methods, and 14.7 liters/ha (76 percent) compared to reduced tillage methods (Jasa 2002). An American Soybean Association survey[4] showed significant reductions in tillage, and therefore in fuel use, by growers of glyphosate-tolerant soybeans. The fuel reductions were estimated as 1.26 gallons per acre, or, for the 56 million acres of glyphosate-tolerant soybeans planted in 2001, 70 million gallons of fuel saved and associated greenhouse gas emissions avoided. These fuel-use reductions translate into reductions of carbon dioxide emissions of 89.44 kg/ha and 40.43 kg/ha, respectively. Overall in 2006, the total carbon dioxide savings associated with the use of GE crops were 1.2 billion kg. This is equivalent to removing 540,000 cars from the streets for a year.

Benefits of the Proposed Rule

The proposed rule would provide benefits by establishing more efficient regulation of GE organisms and activities subject to part 340 and by continuing to provide a high level of protection against risks associated with these organisms and activities. Benefits would also include improved public understanding of and confidence in APHIS' biotechnology regulatory responsibilities, and improved clarity and transparency of the regulatory process. Several amendments of the proposed rule would improve the efficiency of APHIS' biotech regulatory process. Particular proposed changes that should improve the efficiency of the regulations include the elimination of courtesy permits and the establishment of a procedure to evaluate and grant requests for new exemptions from the requirement that GE organisms have a permit to be imported, moved interstate, or released into the environment.

Approving new exemptions could be done without amending the regulations, resulting in considerable time savings

[4] Cited in Fawcett, Richard and Towery, Dan. Conservation Tillage and Plant Biotechnology: How New Technologies Can Improve the Environment By Reducing the Need to Plow. Conservation Technology Information Center, West Lafayette, Indiana.

for regulated parties and reducing APHIS' rulemaking costs. Persons using an exemption would also avoid the costs and delays associated with obtaining a permit for each new planned movement or release of a GE organism covered by the exemption.

APHIS commits considerable resources to issuing courtesy permits not actually required by or needed to implement the part 340 regulations. These courtesy permits have been issued to facilitate the movement of GE organisms that are but whose movement may be hindered due to their similarity to organisms that are subject to part 340. By improving public awareness that such organisms do not need a permit and eliminating the courtesy permit process APHIS would improve efficiency and reduce its regulatory workload, and save time for regulated entities who would no longer make unnecessary courtesy permit requests.

The Agency currently issues environmental release permits, including permits that are used for production of pharmaceutical and industrial compounds sold in commerce. In general, permits for releases of plants producing pharmaceutical or industrial compounds have been limited to a one-year duration. However, the proposed regulations provide a more useful and efficient approach to setting appropriate risk-related conditions in multi-year environmental release permits. Under the proposed system, APHIS would likely increase issuance of multi-year environmental release permits, thereby reducing the time the regulated entities need to spend submitting applications as well as the time APHIS spends reviewing the permit applications.

APHIS' biotechnology operations would be aided by more clarity in terms of required data submissions and administrative procedures. More detail is provided regarding what applicant information is required for each permit application type, and how application information relates to the proposed new permit categories for environmental release permits. These changes, along with more clearly defined categories for the environmental release permits, would potentially reduce the time some entities, large or small, spend on an application or petition process. Increased efficiency benefits may be most helpful to smaller companies and public sector entities, where GE research is generally conducted on a much smaller scale than that of large agri-business enterprises.

The proposal includes provisions to require necessary recordkeeping and reporting but to fine-tune this burden through particularized permit conditions to require only what is needed to ensure regulatory compliance based on individual cases. This should contribute to greater efficiency.

The proposed rule's greater clarity and transparency is expected to enhance the general public's perception of APHIS regulation in this area, with associated benefits from increased support of and compliance with the regulations.

In addition to the information provided in the regulations, APHIS proposes to develop new guidance documents to assist in the preparation and submission of applications.

Costs of the Proposed Rule

There are several cost areas associated with the proposed rule. Costs associated with the proposed rule that regulated entities would incur include costs of learning and adapting procedures to changed requirements, providing more or different information in permit applications, and additional recordkeeping for some entities. The additional recordkeeping burden is discussed below in the Paperwork Reduction Act section. Annual costs resulting from the additional recordkeeping may be estimated as the salary and associated costs for 640 additional hours of recordkeeping divided among 160 respondents.

Many provisions of the proposed regulations are revisions of the current regulations, and it is not expected that familiarization costs would be substantial. However, estimates of these costs are not available and therefore APHIS invites public comment on the costs the regulated community may incur with respect to rule familiarization and changes to their application systems.

Costs to APHIS are currently incurred in the regulatory assessment and review of submitted materials. Because the new permit process is largely similar to the current process, it is expected that ongoing permit processing costs to APHIS would remain essentially unchanged. As a start-up cost to change the permit system to accommodate requirements of the proposed rule, APHIS may potentially incur a one-time additional cost of $500,000. However the current system is adaptable to the new regulations and it is not anticipated that there would be any efficiency loss during the transitional period. APHIS would also potentially incur incremental costs conducting outreach activities for the proposed rule, developing guidance documents to ensure that the regulated community is familiar with the requirements of the rule, and providing staff training that may be necessary. Because of the new definition of the scope of the regulations, APHIS may devote more resources to consultations with regulated parties if they request consultation to determine whether particular GE organisms are or are not subject to the regulations. Such consultation should decrease after the first year or two of implementation, as such determinations of regulated status accumulate and become the basis for guidance of general applicability.

Initial Regulatory Flexibility Analysis

In accordance with the Regulatory Flexibility Act of 1980 (Pub. L. 96–354), this analysis considers the economic impact of the proposed rule on small businesses, small organizations, and small governmental jurisdictions. Section 603 of the Act requires that the initial regulatory flexibility analysis (IRFA) be made available for public comments. This section addresses the IRFA requirements, as stated in Sections 603(b) and 603(c) of the Act.

Reasons Action Is Being Considered

APHIS is taking action to amend 7 CFR part 340, which was promulgated in 1987 under the authority of the Federal Plant Pest Act of 1957 and the Plant Quarantine Act of 1912. These acts were subsequently subsumed within the Plant Protection Act (PPA) of 2000, and the proposed revisions would bring part 340 in alignment with this Act. Advances in biotechnology and accumulation of oversight experience by APHIS have also made it necessary to revise and update the regulations, and in addition, the 2008 Farm Bill (The Food, Conservation, and Energy Act of 2008) enacted most recently contains provisions that need to be incorporated into the proposed rule. The proposed changes would improve the regulatory process by providing greater transparency, flexibility, and efficiency.

Objective and Legal Basis for the Rule

The objectives of this rule are to amend part 340 to provide consistency with the PPA authorities and to incorporate updates and improvements to provide a more efficient regulatory process while controlling potential risk to plant health and the environment. The PPA authorizes the Secretary of Agriculture to implement programs and policies designed to prevent the introduction and spread of plant pests and diseases. Specifically, the Secretary of Agriculture is given the authority under the PPA to prevent the importation or dissemination of plant pests and noxious weeds. To do so, the

Secretary may regulate the importation, interstate movement, and release into the environment of any plant, plant product, biological control organism, noxious weed, article, or means of conveyance that could potentially spread plant pests or noxious weeds.

Description and Estimate of the Number of Small Entities Regulated

The proposed rule may affect a wide range of public and private biotechnology research facilities, GE crop and seed production, food processors, grain processors, and paper producers that fall into various categories of the North American Industry Classification System (NAICS). For the purpose of this analysis and following the Small Business Administration (SBA) guidelines, the potentially affected entities are classified within the following sectors: Agriculture, Forestry, Fishing and Hunting (Sector 11), Manufacturing (Sectors 31–33), Wholesale Trade (Sector 42), Retail Trade (Sector 44 and 45), Transportation (Sectors 48 and 49), and Professional, Scientific and Technical Services (Sector 54).

For the Agriculture, Forestry, Fishing and Hunting sector, the subsectors of Crop Production, Animal Production, Forestry and Logging, and Support Activities for Agriculture and Forestry are potentially affected by this rule. The proposed rule may affect a wide range of establishments in the Crop Production category. Establishments in this category are considered small by SBA standards if annual sales are not more than $0.75 million. According to the 2002 Census of Agriculture, 97 percent of the farming businesses are considered small. Potentially affected crop-producing industries, with their NAICS codes in parentheses, are as follows: Soybean Farming (111110); Oilseed Farming (except soybean) (111120); Dry Pea and Bean Farming (111130); Wheat Farming (111140); Corn Farming (111150); Rice Farming (111160); Oilseed and Grain Combination Farming (111191); All Other Grain Farming (111199); Potato Farming (111211); Other Vegetable (except potato) and Melon Farming (111219); Orange Groves (111310); Citrus (except orange) Groves (111320); Apple Orchards (111331); Grape Vineyards (111332); Strawberry Farming (111333); Berry (except Strawberry) Farming (111334); Tree Nut Farming (111335); Fruit and Tree Nut Combination Farming (111336); Other Noncitrus Fruit Farming (111337); Mushroom Production (111411); Other Food Crops Grown Under Cover (111419); Nursery and Tree Production (111421); Floriculture Production (111422); Tobacco Farming (111910); Cotton Farming (111920); Sugarcane Farming (111930); Hay Farming (111940); Sugar Beet Farming (111950); Peanut Farming (111960); and All other Miscellaneous Crop Farming (111970).

Some aspects of animal production may be affected because some GE plants are used for animal feeds and may have enhanced nutritional value or other benefits. In terms of animal production, potentially affected entities include ones within the following industries: Beef Cattle Ranching and Farming (NAICS 112111); Cattle Feedlots (NAICS 112112); Hog and Pig Farming (NAICS 112210); Sheep Farming (NAICS 112410); Goat Farming (NAICS 112420); and Apiculture (NAICS 112910). Except for Cattle Feedlots, entities in all of these industries are considered small by SBA standards if annual sales are not more than $0.75 million. Cattle Feedlot establishments are considered small by SBA standards if annual sales are not more than $2 million. According to the 2002 Census of Agriculture, 93 percent of Cattle Feedlot businesses, 99 percent of Beef Cattle Ranching and Farming businesses, 81 percent of Hog and Pig Farming businesses, 99 percent of Sheep and Goat farming businesses, and 99 percent of Apiculture businesses are considered small.

For the Forestry and Logging subsector the potentially affected establishments are classified within Timber Tract Operations (NAICS 113110); Forest Nursery and Gathering of Forest Products (NAICS 113210); and Logging (NAICS 113310). Establishments in the category of Timber Tract Operations and Forest Nursery and Gathering of Forest Products are considered small by SBA standards if annual sales are not more than $6.5 million and establishments in the category of Logging are considered small if employment is not more than 500. According to the 2002 Survey of Business Owners, 99 percent of establishments in the Logging category are considered small. Neither the Census of Agriculture nor the Economic Census tracks revenue for establishments classified within Timber Tract Operations and Forest Nursery and Gathering of Forest Products.

In terms of Support Activities for Agriculture and Forestry, the potentially affected establishments are classified within Cotton Ginning (NAICS 11511); Soil Preparation, Planting, and Cultivating (NAICS 115112); Crop Harvesting (NAICS 115113); Postharvest Crop Activities (NAICS 115114); Farm Management Services (115116) Support Activities for Animal Production (NAICS 115210); and Support Activities for Forestry (NAICS 115310). Establishments in these categories are considered small by SBA standards if annual sales are not more than $6.5 million. However, neither the Census of Agriculture nor the Economic Census reports revenue for these establishments.

Entities that may be directly affected by the proposed rule in the Manufacturing Sector are classified within Ethyl Alcohol Manufacturing (NAICS 325193); Pesticide and Other Agricultural Chemical Manufacturing (NAICS 325320); Pharmaceutical Preparation Manufacturing (NAICS 325412); and Medicinal and Botanical Manufacturing (NAICS 325411). Establishments in the Ethyl Alcohol Manufacturing category are considered small if they employ not more than 1,000 persons and those in the category of Pesticide and Other Agricultural Chemical Manufacturing (NAICS 325320) are considered small if they employ not more than 500 persons. For both the Pharmaceutical Preparation Manufacturing (NAICS 325412); and Medicinal and Botanical Manufacturing (NAICS 325411) categories, establishments are considered small if they employ not more than 750 persons. According to the 2002 Economic Census, 98 percent of the establishments in the Chemical Manufacturing Sector had fewer than 500 employees and 99 percent had fewer than 1000. Therefore, businesses in the chemical manufacturing are predominantly small by SBA standards.

In terms of Wholesale Trade, entities that would be potentially affected may be found in the following categories: Fresh Fruit and Vegetable Merchant Wholesalers (NAICS 424480); Other Grocery and Related Products Merchant Wholesalers (NAICS 424490); Grain and Field Bean Merchant Wholesalers (NAICS 424510); Other Farm Product Raw Material Merchant Wholesalers (NAICS 424590); Farm Supplies and Merchant Wholesalers (NAICS 424910); and Flower, Nursery Stock, and Florists' Supplies Merchant Wholesalers (NAICS 424930). Establishments in the above categories are considered small by SBA standards if they employ not more than 100 persons. According to the 2002 Survey of Business Owners, 97 percent of the establishments in this category employed fewer than 100 people and are considered small by SBA standards.

Retail Trade, establishments that would be affected by the rules are in the following categories: Nursery and Garden Centers (NAICS 444220); Supermarkets and Other Grocery Stores (NAICS 445110); Fruit and Vegetable

Markets (NAICS 445230); All Other Specialty Food Stores (NAICS 445299); Food (Health) Supplement Stores (NAICS 446191); Warehouse Clubs and Superstores (NAICS 452910); and Florist (NAICS 453110). Establishments in the Nursery and Garden Center, Fruit and Vegetable Markets, All other Specialty Food Stores, Food (Health) Supplement Stores; and Florist categories are considered small by SBA standards if annual sales are not more than $6.5 million. Supermarkets and Other Grocery Stores are considered small by SBA standards if annual sales are not more than $25 million. While the Economic Census reports total annual sales, the Census does not provide a breakdown of these establishments by revenue categories.

In terms of the Transportation sector, the potentially affected entities are in the category Farm Product Warehousing and Storage (NAICS 493130). Establishments in this category are considered small by SBA standards if annual sales are not more than $23.5 million. However, the Economic Census reports only total revenue for all establishments in this category.

In terms of Professional, Scientific and Technical Services, establishments in the category of Research and Development in the Physical, Engineering, and Life Sciences (NAICS 54170) may be affected. Establishments in this category are considered small by SBA standards if they employ not more than 500 persons. According to 2002 Economic Census, 82 percent of the establishments in this category are considered small.

Although information was not available on the business sizes for all potentially affected establishments, based on the foregoing information we can assume that the majority of the entities that may be affected by the proposed rule are small by SBA standards.

Given the aforementioned, a review of entities that have made application requests to APHIS shows that of the 420 applicants for the last 6 years, 263 were universities and colleges and public and private research institutions. The remainder of the applicants fall under various NAICS classification codes specified above but given time constraints their business size could not be readily determined. We were able to ascertain that the 263 institutions (63 percent) are large by SBA standards as they fall under NAICS code 54170 Research and Development in Physical Science. Establishments in this category are considered small by SBA standards if they employ not more than 500 persons. Even though the 2002 Economic Census suggests that 82 percent of the establishments in this category are considered small, the majority of applicants to APHIS are large by SBA standards.[5]

Description and Estimate of Compliance Requirement

The proposed rule would require additional and modified information collections through recordkeeping, reporting, and notifications to APHIS when certain events occur. The proposed application process requires certain new information. The current and proposed rules both require submission of reports following an environmental release or field test, but the proposed requirement is more specific about the contents of such reports. Both the current and proposed rules require APHIS to be notified if an unauthorized release occurs or if during release the GE organism is found to have characteristics substantially different from those anticipated by the permit. The proposed rule is more specific about the types of records that must be kept for importations, interstate movements, and environmental releases, where the current regulations left more of these details to be specified only in permit conditions. In terms of record retention requirements, the proposed rule spells out a 2-year retention for records indicating that a GE organism imported or moved interstate reached its intended destination, and a 5-year retention for all other required records. By providing more specific information on what records are required, the proposed rule should alleviate some current burden that may result from persons keeping unnecessary records. In addition, APHIS has established the Biotechnology Quality Management System (BQMS), which is a voluntary compliance assistance unit within USDA APHIS. BQMS would facilitate the regulatory efforts of USDA APHIS by conducting outreach activities and providing compliance assistance to the regulated community. This would lessen any burden of the proposed rule to the regulated community.

Duplication, Overlap, and Conflict With Existing Rules and Regulations

APHIS has identified areas where the proposed rule will need to be closely coordinated with other Federal rules and statutory authorities. Coordination has been an important aspect of the daily implementation of the current regulation, and APHIS foresees additional areas for coordination under the proposed rule. In particular, APHIS will coordinate with the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA). FDA regulates GE organisms under the authority of the Federal Food, Drug and Cosmetic Act and the Public Health Service Act (42 U.S.C. 262 *et seq.*), as appropriate. The EPA regulates plant-incorporated protectants under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and certain biological control organisms under the Toxic Substances Control Act (TSCA). As examples of areas that need coordination, some of the plant-incorporated protectants regulated by EPA are also subject to APHIS requirements under the PPA. Also, FDA is the primary U.S. agency responsible for ensuring the safety of commercial food and food additives, and FDA authority extends to any nonpesticidal substance that may be introduced into a new GE plant and that is expected to become a component of food. The proposed regulations would clarify the regulatory scope and procedures used by APHIS relative to these other agencies and improve the coordination process.

Significant Alternatives to the Rule

APHIS considered several significant alternatives during development of this proposed rule. We have compared the selected alternatives to others that were not selected to evaluate their feasibility and to consider whether any alternatives provide ways to minimize significant economic impacts on small entities. We have not identified any selected alternative that imposes disproportionate costs on small businesses, or any non-selected alternative that would both achieve the regulatory purposes and reduce costs for small businesses.

The selected alternative regarding the scope of the regulatory oversight was to add considerations of noxious weed risk in addition to evaluating plant pest risks, and to use genetic transformation, coupled with a determination by the Administrator as to whether a GE organism met certain risk-based criteria, as the trigger for regulation. Other alternatives considered included continuing to base the scope of regulation only on plant pest risks, or trying to develop a set of solely trait-based criteria that could be used to predict what articles would be regulated without the need for determinations by the Administrator. The first of these alternatives could have resulted in costs from damages caused by a GE plant with

[5] The size determination was made using public information about these entities. This information was primarily obtained from the entities' Web sites.

noxious weed aspects that was not regulated under the plant pest risks standard. The second alternative was not considered technically feasible, and could also have resulted in costs for persons who erroneously decide their GE plant is not within the scope of the regulations, but are overruled by a later determination by the Administrator that the GE plant is regulated.

The selected alternative for providing transparency and predictability to the permitting system was to establish permit categories for environmental releases of plants based on newly devised criteria. We also considered evaluating all requests for environmental release permits on a case-by-case basis, without categories. This alternative would have resulted in less predictability for applicants, and likely would have increased their costs for information collection because applications known to be in a particular category can contain less information about non-relevant areas.

The selected alternative regarding the duration period for permits was to make multi-year permits for interstate movement and importation more feasible by removing the one-year limit for interstate movement permits and the requirement to obtain a new importation permit for each imported shipment. We also considered alternatives to maintain either the current or alternative specific time limits for such permits. These alternatives would have resulted in additional costs for applicants who would have to reapply for permits, rather than having the original permit issued with an appropriate duration.

C. Executive Order 12372

This program/activity is listed in the Catalog of Federal Domestic Assistance under No. 10.025 and is subject to Executive Order 12372, which requires intergovernmental consultation with State and local officials. (See 7 CFR part 3015, subpart V.)

D. Executive Order 12988

This proposed rule has been reviewed under Executive Order 12988, Civil Justice Reform. If this proposed rule is adopted: (1) No State or local laws or regulations would be preempted by this rule; (2) no retroactive effect will be given to this rule; and (3) administrative proceedings will not be required before parties may file suit in court challenging this rule.

E. Paperwork Reduction Act

In accordance with section 3507(d) of the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 *et seq.*), the information collection or recordkeeping requirements included in this proposed rule have been submitted for approval to the Office of Management and Budget (OMB). The information collection or recordkeeping requirements in current 7 CFR part 340 have been approved under OMB Control No. 0579–0085. Please send written comments to the Office of Information and Regulatory Affairs, OMB, Attention: Desk Officer for APHIS, Washington, DC 20503. Please state that your comments refer to Docket No. APHIS–2008–0023. Please send a copy of your comments to: (1) Docket No. APHIS–2008–0023, Regulatory Analysis and Development, PPD, APHIS, Station 3A–03.8, 4700 River Road Unit 118, Riverdale, MD 20737–1238, and (2) Clearance Officer, OCIO, USDA, room 404–W, 14th Street and Independence Avenue SW., Washington, DC 20250. A comment to OMB is best assured of having its full effect if OMB receives it within 30 days of publication of this proposed rule.

This proposed rule contains certain information collection and recordkeeping requirements that would apply to persons and their agents engaged in the importation, interstate movement, or release into the environment of any GE organism that is subject to the regulations. The majority of the requirements would apply to persons moving GE organisms under a permit issued by APHIS, but some requirements also apply to persons engaged in regulatory activities with GE organisms even when no permit is required, e.g., when they are exempted from the interstate movement permit requirement.

The proposed information and recordkeeping requirements are found in § 340.3, *Permit conditions*, and in § 340.7, *Compliance, enforcement, and remedial action*. Permit conditions for individual permits issued under the regulations may also require that certain records relevant to the particular movement must be kept.

The proposed permit conditions for shipments imported or moved interstate include maintaining records of the same types of information that the current regulations require to be on the package labeling of such shipments (nature and quantity, sender, destination, permit number, etc.) We believe that most persons shipping or importing GE organisms already maintain such records as part of normal business practices.

The proposed permit conditions for environmental releases include keeping records of all protocols or guidelines used to direct any environmental release. The current regulations already require persons conducting an environmental release under permit or notification to create and submit to APHIS a field test report, and in many cases the protocol or guidelines would normally be included in these field reports. This proposed change would require that the protocols or guidelines be kept in all cases as distinctly identifiable records, which may cause some increase in recordkeeping burden.

In some particular environmental release cases where higher risk levels make it necessary, the proposed rule would allow APHIS to add a special permit condition requiring the permit holder to maintain and make available to APHIS written manuals or protocols describing how specified permit conditions will be met, such as management practices used for the environmental release, training, communications, and identity preservation systems. This would be used in cases where it is deemed necessary to provide specific guidance in addition to the proposed general condition for all permits (i.e., that the holder must keep records related to permitted activities of sufficient quality and completeness to demonstrate compliance with all permit conditions and requirements under this part). Another proposed permit condition would require permit holders to develop and keep a written contingency plan to respond to any unauthorized environmental release. Both of these recordkeeping requirements would be added because some researchers or developers were found to be unclear about what management and communications practices were needed to prevent unauthorized releases, and also about their responsibilities and the measures they must take in the event of an unauthorized release.

The proposed procedure to apply for an environmental release permit requires applicants to submit a great deal of information characterizing the nature of the GE organism, the type of movement and release planned, plans and methods used to prevent unauthorized releases, and other matters. Most of the same information is obtained through the current application process, which allows the Administrator to require an applicant to submit any additional information that is needed for adequate evaluation of the application. The proposed application procedure is more specific in describing what information is required, and may result in a slight increase in the amount of information submitted with the average application.

The reporting burden for permit holders under the proposed rule would be similar to the burden under the

current regulations. In both cases they must submit reports of all field tests to APHIS, report any unauthorized releases, and submit any additional reports required as individual permit conditions in their permits.

The current regulations do not specify record retention periods, although some permits APHIS issued included specific retention requirements as permit conditions. This proposal would require that records associated with an importation or interstate shipment must be retained for at least 2 years after completion of the movement, and all other records (e.g., regarding environmental releases) must be retained for at least 5 years after completion of all obligations required under a relevant permit or exemption.

We are soliciting comments from the public (as well as affected agencies) concerning our proposed information collection and recordkeeping requirements. These comments will help us:

(1) Evaluate whether the proposed information collection is necessary for the proper performance of our agency's functions, including whether the information will have practical utility;

(2) Evaluate the accuracy of our estimate of the burden of the proposed information collection, including the validity of the methodology and assumptions used;

(3) Enhance the quality, utility, and clarity of the information to be collected; and

(4) Minimize the burden of the information collection on those who are to respond (such as through the use of appropriate automated, electronic, mechanical, or other technological collection techniques or other forms of information technology; e.g., permitting electronic submission of responses).

Estimate of burden: Public reporting burden for this collection of information is estimated to average 2 hours per response.

Respondents: Public and private biotechnology research facilities, GE crop and seed producers, food processors, grain processors, and paper producers that fall into various categories of the North American Industry Classification System.

Estimated annual number of respondents: 160.

Estimated annual number of responses per respondent: 2.

Estimated annual number of responses: 320.

Estimated total annual burden on respondents: 640 hours.

Copies of this information collection can be obtained from Celeste Sickles, the Agency Information Management Specialist, at (301) 851–2908.

F. E-Government Act Compliance

The Animal and Plant Health Inspection Service is committed to compliance with the E-Government Act to promote the use of the Internet and other information technologies, to provide increased opportunities for citizen access to Government information and services, and for other purposes. For information pertinent to E-Government Act compliance related to this proposed rule, please contact Mrs. Celeste Sickles, the Agency Information Management Specialist, at (301) 851–2908.

List of Subjects in 7 CFR Part 340

Administrative practice and procedure, Biotechnology, Genetic engineering, Imports, Packaging and containers, Permits, Plant diseases and pests, Noxious weeds, Transportation.

Accordingly, we propose to revise 7 CFR part 340 to read as follows:

PART 340—IMPORTATION, INTERSTATE MOVEMENT, AND RELEASE INTO THE ENVIRONMENT OF CERTAIN GENETICALLY ENGINEERED ORGANISMS

Sec.

340.0 Scope and general restrictions.
340.1 Definitions.
340.2 Procedure for permits.
340.3 Permit conditions.
340.4 Conditional exemptions from the requirement for a permit for interstate movement.
340.5 Petition for new conditional exemptions from the requirement for a permit.
340.6 Petition for nonregulated status.
340.7 Compliance, enforcement, and remedial action.
340.8 Confidential business information.
340.9 Costs and charges.

Authority: 7 U.S.C. 7701–7772 and 7781–7786; 31 U.S.C. 9701; 7 CFR 2.22, 2.80, and 371.3.

§ 340.0 Scope and general restrictions.

(a) In order to prevent the unauthorized introduction or dissemination of a plant pest or noxious weed, no person shall import, move interstate, or release into the environment genetically engineered organisms described in paragraph (b) of this section, unless the importation, interstate movement, or release into the environment:

(1) Is authorized under a permit issued by the Administrator in accordance with § 340.2, or

(2) Is exempt from the requirements for a permit in accordance with § 340.4 or § 340.5, or

(3) Is approved for nonregulated status in accordance with § 340.6 or has previously been approved for nonregulated status pursuant to former regulations under this part, or

(4) Is excluded in accordance with paragraph (d) of this section.

(b) Genetically engineered organisms whose importation, interstate movement, or release into the environment is subject to the regulations in this part are:

(1) Genetically engineered plants if:

(i) The unmodified parent plant from which the GE plant was derived is a plant pest or noxious weed, or

(ii) The trait introduced by genetic engineering could increase the potential for the GE plant to be a plant pest or noxious weed, or

(iii) The risk that the GE plant poses as a plant pest or noxious weed is unknown, or

(iv) The Administrator determines that the GE plant poses a plant pest or noxious weed risk.

(2) Genetically engineered non-plant, non-vertebrate organisms if:

(i) The recipient organism can directly or indirectly injure, cause damage to, or cause disease in plants or plant products; or

(ii) The GE organism has been engineered in such a way that it may increase the potential for it to be a plant pest: or

(iii) The risk that the GE organism poses as a plant pest is unknown, or

(iv) The Administrator determines that the GE organism poses a plant pest risk.

(3) *Opportunity to consult APHIS.* Any person may contact APHIS to discuss how the criteria of this paragraph apply in the case of a particular GE organism or group of organisms.

(c) The Administrator may issue permits for the importation, interstate movement, or release into the environment of certain genetically engineered organisms described in paragraph (a) of this section. These permits may include such requirements or conditions as the Administrator deems necessary to prevent the unauthorized introduction or dissemination of a plant pest or noxious weed. The Administrator may also designate certain exemptions from the requirement to obtain permits. The Administrator may also approve for nonregulated status a genetically engineered organism described in paragraph (a) of this section for which a determination has been made by the Administrator that the organism is unlikely to be a plant pest or noxious weed.

(d) Genetically engineered microorganisms that are regulated as biological control organisms under the Federal Insecticide, Fungicide, and Rodenticide Act are not subject to the regulations in this part. Genetically engineered microorganisms where the recipient microorganism is not a plant pest and which has resulted from the addition of genetic material from a donor organism where the material is well characterized and contains only non-coding regulatory regions are not subject to the regulations in this part.

§ 340.1 Definitions.

Terms used in the singular form in this part shall be construed as the plural, and vice versa, as the case may demand. The following terms, when used in this part, shall be construed, respectively, to mean:

Administrator. The Administrator of the Animal and Plant Health Inspection Service (APHIS) or any other employee of APHIS to whom authority has been, or may be, delegated to act in the Administrator's stead.

Animal and Plant Health Inspection Service (APHIS). An agency of the United States Department of Agriculture.

Confidential business information, CBI. Information such as trade secrets or commercial or financial information that may be exempt from disclosure under Exemption 4 of the Freedom of Information Act (FOIA), because disclosure could reasonably be expected to cause substantial competitive harm. USDA regulations on how the agency will handle CBI and how to determine what information may be exempt from disclosure under FOIA (5 U.S.C. 552) are found at 7 CFR 1.12.

Contained facility, contained structure. A physical structure designed to minimize release into the outdoor environment. Examples of contained structures include, but are not limited to, laboratories, containment greenhouses, bioreactors, and fermenters.

Contingency plan. A written plan stating how the responsible person will respond in the event of the unauthorized environmental release of GE organisms.

Donor organism. The organism from which genetic material is obtained for transfer to the recipient organism in the process of genetic engineering.

Environmental release. See definition of *Release into the environment.*

Exempt, exempted, exemption from permit. A determination by the Administrator that the importation, interstate movement, and/or release into the environment of an organism or class of organisms described in § 340.0(a) is not subject to the requirement to have a permit under this part. An exemption from one type of permit (e.g., interstate movement) does not remove remaining obligations to obtain other permits under this part.

Genetic engineering. The genetic modification of organisms by recombinant DNA techniques.

Genetically engineered, GE. A term applied to organisms that have been produced by genetic engineering, e.g., GE organisms, GE plants.

Import and importation. To move into, or the act of movement into, the territorial limits of the United States.

Inspector. Any employee of the Animal and Plant Health Inspection Service, U.S. Department of Agriculture, or other person, authorized by the Administrator, in accordance with law to enforce the provisions of this part.

Interstate movement. Movement from any State into or through any other State.

Means of conveyance. Any personal property used for, or intended for use for, the movement of any other personal property. This specifically includes, but is not limited to, automobiles, trucks, railway cars, aircraft, boats, freight containers, and other means of transportation.

Nonregulated status. A determination by the Administrator that an organism described in § 340.0(a) is not subject to any of the regulatory requirements of this part.

Noxious weed. Any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment.

Organism. Any active, infective, or dormant stage or life form of an entity characterized as living, including vertebrate and invertebrate animals, plants, bacteria, fungi, mycoplasmas, mycoplasma-like organisms, as well as entities such as viroids, viruses, or any entity characterized as living, related to the foregoing.

Permit. A written authorization by the Administrator for the importation, interstate movement, and/or release into the environment of a GE organism under this part.

Person. Any individual, partnership, corporation, company, joint venture, society, association, or other legal entity.

Plant. Any plant (including any plant part) for or capable of propagation, including trees, tissue cultures, plantlet cultures, pollen, shrubs, vines, cuttings, grafts, scions, buds, bulbs, roots, and seeds.

Plant pest. Any living stage of any of the following that can directly or indirectly injure, cause damage to, or cause disease in any plant or plant product: A protozoan, a nonhuman animal, a parasitic plant, a bacterium, a fungus, a virus or viroid, an infectious agent or other pathogen, or any other living stage similar to or allied with any of these organisms.

Plant product. Any flower, fruit, vegetable, root, bulb, seed, or other plant part that is not included in the definition of plant; or any manufactured or processed plant or plant part.

Recipient organism. The organism that will receive the genetic material from a donor organism in the process of genetic engineering (once the organism is engineered it is referred to as the genetically engineered (GE) organism).

Release into the environment. Dispersal beyond the constraints of a contained facility or secure shipment. Synonymous with the term environmental release.

Responsible person. The person who has control and will maintain control over a GE organism during its importation, interstate movement, or release into the environment and assures compliance with all conditions contained in any applicable permit or exemption as well as other requirements in this part. A responsible person shall be at least 18 years of age and be a legal resident of the United States or designate an agent who is at least 18 years of age and a legal resident of the United States.

Secure shipment. Shipment in a container or a means of conveyance of sufficient strength and integrity to withstand leakage of contents, shocks, pressure changes, and other conditions incident to ordinary handling in transportation.

Signature, signed. The discrete, verifiable symbol of an individual which, when affixed to a writing with the knowledge and consent of the individual, indicates a present intention to authenticate the writing. This includes electronic signatures when authorized by the Administrator.

State. Any State of the United States, the District of Columbia, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, the Virgin Islands of the United States, and any other Territories, Possessions, or Districts of the United States.

State or tribal regulatory official. State or tribal official with responsibilities for plant health, or any other duly designated State or tribal official, in the

State or on the tribal lands where the importation, interstate movement, or release into the environment is to take place.

United States. All of the States.

Write, writing, written. Any document or communication required by this part to be in writing may also be provided by electronic communication when authorized by the Administrator.

§ 340.2 Procedure for permits.

(a) *General.* A permit is required for the importation, interstate movement, or release into the environment of any GE organism that is subject to this part, as described in § 340.0, The responsible person seeking a permit for the importation, interstate movement, or release into the environment of such organisms shall submit a written application for a permit to APHIS in accordance with paragraph (c) of this section and obtain the permit prior to the importation, interstate movement, or release into the environment.

(b) *Types of permits.* The Administrator may issue the following three types of permits under this part.

(1) *Import permit.* Import permits are for secure shipment via any means of conveyance from outside the United States into contained facilities within the United States.

(2) *Interstate movement permit.* Interstate movement permits are for secure shipment via any means of conveyance from a contained facility in any State into or through any other State to another contained facility.

(3) *Environmental release permit.* Environmental release permits are for the environmental release of GE organisms. In cases in which importation and interstate movements will occur incidental to an environmental release, the importation and interstate movements will also be authorized under the environmental release permit.

(c) *Permit application information requirements.* Applicants must submit to APHIS sufficient information about the specific nature of the GE organism and the particular proposed permit conditions, so that the Administrator is able to consider whether the proposed importation, interstate movement, or release into the environment is likely to result in the introduction or dissemination of a plant pest or noxious weed. The basic information required in permit applications is described in this paragraph. The type and level of detail needed for the Administrator to issue a permit may vary by type of permit. For environmental releases, application information will be used to sort proposed releases of GE organisms into administrative categories described in paragraph (d) of this section. Applicants should consult with APHIS prior to applying for permits in order to obtain further guidance as to what additional information the Administrator may require to be submitted with the application.

(1) *Information required in all permit applications.* Each application must include all of the following information, and any other information specified for individual types of permits as described in this paragraph:

(i) The name, title, and contact information (e.g., mailing address, e-mail, telephone and fax numbers) of the responsible person;

(ii) The type of permit sought (importation, interstate movement, or environmental release, and if the permit is for environmental release, which category);

(iii) Information necessary to identify and characterize the GE organism(s) for which a permit is sought, including:

(A) The scientific names of all donor and recipient species plus any designations used for the GE organism(s) (e.g., strain, line, variety);

(B) The form of the GE organism (e.g., seeds, rootstocks, tubers, spores, larvae, eggs) and the amount (e.g., numbers, total weight or volume); and a description of any biological material accompanying the GE organism under permit (e.g., culture medium, or host organisms, etc.);

(C) The anticipated phenotype of the GE organism and the nature of the inserted sequences or other genetic modification intended to confer the phenotype;

(D) Intended uses of the GE organism after the termination of the importation, interstate movement, or environmental release (e.g., contained research in laboratories or containment greenhouses, culturing, propagation, breeding, processing for analysis or manufacture, sale and distribution for consumption); and

(E) Description of how the GE organism will be marked, labeled, or otherwise identified during the importation, interstate movement, or environmental release;

(iv) The proposed time frame (estimated start and duration) within which the importation(s), interstate movement(s) or environmental release(s) will occur;

(v) Description of how permit requirements will be communicated to persons having contact with the GE organism under permit;

(vi) Description of any training given to persons having contact with the GE organism under permit, including but not limited to detailed information on how this training will facilitate compliance with conditions imposed under the permit and any other regulatory requirements under this part; and

(vii) A certification statement signed by the responsible person that certifies that the application information is correct.

(2) *Additional information required in all applications for importation permits, interstate movement permits, and all environmental release permits that include importation or interstate movement.*

(i) The location(s) of the origin(s) and destination(s), including information on the addresses, and contact details of the sender(s) and recipient(s), if different from the responsible person.

(ii) A description of the method of secure shipment.

(iii) A description of the manner in which packaging material, shipping containers, and any other material accompanying the GE organism will be disposed.

(3) *Additional information required in all environmental release permit applications.* Information should address the persistence risk and potential harm of the GE organism in the environment, including but not limited to:

(i) A description of how the phenotype of the GE organism differs from the phenotype of the recipient organism, particularly with respect to potential interactions with and its likelihood of persistence in the environment.

(ii) The location and size of all proposed release sites, including area, geographic coordinates, addresses, and contact information of a person at each release site, if different from the responsible person. Include information about the ecology and agronomy of each site, including but not limited to:

(A) Presence of any wild or cultivated species that are sexually compatible with the GE organism;

(B) Presence of any Federally-listed threatened or endangered species that could interact with the GE organism during the release;

(C) Presence of any designated critical habitat, or habitat proposed for designation, in the area of the release site; and

(D) Land use history of the site and adjacent areas.

(iii) A description of the site management practices and control procedures designed to make it unlikely that there will be unauthorized introduction or dissemination of the GE organism beyond the proposed area and

the permit time frame of release. Each of the descriptions shall include:

(A) Description of the methods and stages of transport of the GE organism from a contained facility to the environmental release site, and any storage methods used at the site;

(B) Description of methods of planting, inoculation, or release; any reproductive or cultural controls; methods of treatment and harvest used for the GE organism; and a proposed plan for monitoring the site for pests, diseases, and effects on other organisms during the time the GE organism is released;

(C) Description of the methods and stages of transport of the GE organism from release site back into contained facilities, or methods of devitalization at the site(s) of the environmental release;

(D) Description of the cleaning, disinfection, or other methods used to make it unlikely that unauthorized dissemination of the GE organism into the environment could occur via means of conveyance and other articles (e.g., planters, harvesters, containers);

(E) Description of any post-release land use practices, including any monitoring plans to ensure that the GE organism or its progeny are unlikely to reproduce and disseminate in the environment after the termination of the release (e.g., managing volunteer plants); and

(F) Description of the contingency plans associated with the release.

(d) *Administrator action on permit applications.* An initial review should generally be completed by APHIS within 15 days of the receipt of the application for importation or interstate movement permits, and within 30 days for environmental release permits. An application will be considered complete when the Administrator determines that it includes all information required by this section and any additional information that the Administrator determines is needed for review. If necessary after its initial evaluation of an application, APHIS will notify the applicant in writing if the submitted application information is incomplete, and the applicant will be provided the opportunity, without prejudice, to revise the application information to meet the needs for administrative processing and scientific review. Once the Administrator has determined that an application is complete, the Administrator will commence review. The APHIS review should generally be completed within 60 days after it is determined to be complete for importation and interstate movement permits, and within 120 days after it is determined to be complete for environmental release permits.

(1) *Administrative categories for environmental releases.* The Administrator will use the following categories to efficiently administer the program and tailor regulatory oversight in a manner that is commensurate with risk. Environmental releases of GE plants are assigned to one of four categories (A–D), using the factors described in (i–iv). A fifth category (E) is for environmental releases of all non-plant organisms; applications in this category will be reviewed on a case-by-case basis.

(i) *Initial sorting into categories.* The Administrator will use the following factors to initially sort environmental releases into administrative categories.

(A) Persistence of the nonmodified plant, ranked as follows:

(*1*) *Low:* Populations of the recipient plant are unlikely to persist in the environment without human intervention, and the recipient plant has no interfertile wild relatives in the United States.

(*2*) *Moderate:* Populations of the recipient plant are known to be weakly persistent in the environment without human intervention, or the recipient plant has interfertile wild relatives in the United States.

(*3*) *High:* Populations of the recipient plant are known to be strongly persistent in the environment without human intervention, or the recipient plant has interfertile wild relatives in the United States which are aggressive colonizers.

(*4*) *Severe:* The recipient plant is a Federally-listed noxious weed or is known to be similarly aggressive in its ability to colonize and persist in the environment without human intervention.

(B) Potential harm or damage of the engineered traits, ranked as follows:

(*1*) *Low:* Any new proteins or substances produced are unlikely to be toxic or otherwise cause serious harm to humans, vertebrate animals, or invertebrate organisms upon consumption of or contact with the plant or plant parts; and

(*i*) No morphological changes which could cause mechanical injury or damage; and

(*ii*) Introduced sequences are known not to result in plant disease, and confers no or very low increased disease susceptibility.

(*2*) *Moderate:* Any new proteins or substances produced are unlikely to be toxic or otherwise cause serious harm to humans or vertebrate animals upon consumption of or contact with the plant or plant; or

(*i*) Novel resistance to the application of an herbicide; or

(*ii*) Novel ability to cause mechanical injury or damage; or

(*iii*) Produces proteins or substances that are associated with plant disease that are not prevalent or endemic in the area of release, or that confer an increased susceptibility to disease.

(*3*) *High:* Any new proteins or substances produced may be toxic or to otherwise cause serious harm to humans or vertebrate animals, upon consumption of or contact with the plant or plant parts; or

(*i*) Produces an infectious entity which can cause disease in plants.

(*4*) *Severe:* Any new proteins or substances produced are known or likely to be highly toxic or fatal to humans or vertebrate animals, upon consumption of or contact with the plant or plant parts.

(C) Environmental releases will be initially sorted into administrative categories A–D as shown in Table 1, based upon the persistence risk and potential harm described in paragraphs (d)(1)(i)(A) and (B) of this section.

TABLE 1 TO § 340.2(d)(1)—INITIAL SORTING INTO PERMIT ADMINISTRATIVE CATEGORIES (A, B, C, AND D) FOR ENVIRONMENTAL RELEASES OF GE PLANTS, BASED UPON PERSISTENCE RISK OF THE RECIPIENT PLANT SPECIES AND POTENTIAL HARM OR DAMAGE OF THE ENGINEERED TRAIT

Persistence*	Potential harm or damage of engineered trait			
	Low	Moderate	High	Severe
Low	A	A	C	D
Moderate	A	B	C	D
High	B	B	C	D

TABLE 1 TO § 340.2(d)(1)—INITIAL SORTING INTO PERMIT ADMINISTRATIVE CATEGORIES (A, B, C, AND D) FOR ENVIRONMENTAL RELEASES OF GE PLANTS, BASED UPON PERSISTENCE RISK OF THE RECIPIENT PLANT SPECIES AND POTENTIAL HARM OR DAMAGE OF THE ENGINEERED TRAIT—Continued

Persistence*	Potential harm or damage of engineered trait			
	Low	Moderate	High	Severe
Severe	D	D	D	D

*Persistence risk of the recipient plant species.

(2) *Modification of initial sorting based upon additional considerations.* Following initial sorting using the factors described in paragraph (1)(i) of this section, the Administrator may reassign the environmental release to a different category based upon one or more of the following factors:

(i) How the recipient plant is used;

(ii) Whether the added trait significantly alters the persistence risk of the GE plant;

(iii) Whether the gene function is known and based upon empirical observation of the added trait in the same species; and

(iv) Any other information the Administrator deems relevant to the risk of introduction or dissemination of a plant pest or noxious weed.

(3) *APHIS review and assignment of permit conditions.* The Administrator will conduct a review and assign appropriate permit conditions so that the proposed activity will be conducted in a manner that makes it unlikely to result in the introduction and dissemination of a plant pest or noxious weed.

(4) *State or tribal review and comment.* The Administrator will submit for notice and review a copy of the permit application and any permit conditions to the appropriate state or tribal regulatory official. Comments received from the state or tribal regulatory official may be considered by the Administrator prior to permit issuance.

(5) *Site inspection.* Prior to and after permit issuance, an inspector may inspect the sites or the means of conveyance associated with the proposed importation, interstate movement, or release into the environment. The responsible person must allow any such inspections.

(6) *Issuance of a permit.* The Administrator may issue a permit if the Administrator concludes that the actions allowed under the permit are unlikely to result in the introduction or dissemination of a plant pest or noxious weed.

(i) Prior to the issuance of a permit, the responsible person must agree in writing, in a manner prescribed by the Administrator, that the responsible person and all agents of the responsible person will comply with the permit conditions. The Administrator will deny the permit application if the responsible person does not agree that both the responsible person and all of his or her agents will comply with all of the permit conditions.

(ii) If a permit is issued, the permit will include specific permit conditions required by the Administrator in accordance with § 340.3. If a permit is denied, within a reasonable time thereafter the applicant will be informed in writing of the reasons why the permit was denied and will be given the opportunity to appeal the denial in accordance with the provisions of paragraph (g) of this section.

(e) *Denial or revocation of a permit.* Permits may be denied or revoked in accordance with this paragraph.

(1) *Denial.* The Administrator may deny an application for a permit if:

(i) The Administrator cannot conclude based on the application that the actions proposed under the permit are unlikely to result in introduction or dissemination of a plant pest or noxious weed; or

(ii) The Administrator receives information apart from the application that precludes a conclusion by the Administrator that the actions proposed under the permit would be unlikely to result in the introduction or dissemination of a plant pest or noxious weed; or

(iii) The Administrator determines that the responsible person or any agent of the responsible person has failed to comply at any time with any provision of this part. This would include failure to comply with the conditions of any permit issued.

(2) *Revocation.* The Administrator may revoke a permit if:

(i) The Administrator receives information subsequent to issuing a permit and makes a determination based upon this information that the circumstances have changed such that actions under the permit would be likely to result in the introduction or dissemination of a plant pest or noxious weed; or

(ii) The Administrator determines that the responsible person or any agent of the responsible person has failed to comply at any time with any provision of this part. This would include failure to comply with the conditions of any permit issued.

(f) *Notice of revocation.* The Administrator may revoke, either orally or in writing, any permit which has been issued. If the revocation is oral, the Administrator will communicate the revocation and the reasons for it in writing as promptly as circumstances allow.

(g) *Appeal of denial or revocation of permit.* Any person who has been denied a permit or had a permit revoked may appeal the decision in writing to the Administrator within ten days after receiving the written notification of the revocation or denial. The appeal shall state all of the facts and reasons upon which the person relies to assert that the permit was wrongfully revoked or denied. The Administrator will grant or deny the appeal, in writing, stating the reasons for the decision as promptly as circumstances allow. Upon request of the applicant, a hearing may be held to resolve any conflict as to any material fact. Rules of practice concerning such a hearing will be adopted by the Administrator. This administrative remedy must be exhausted before a person can file suit in court challenging the denial or revocation of a permit.

(h) *Amendment or transfer of permits.* Permits issued under this part may only be amended or transferred in accordance with this section.

(1) *Amendment at responsible person's request.* Where circumstances have changed so that a responsible person desires to have the permit amended, such responsible person must submit a written justification and provide supporting information to APHIS. The Administrator will review the amendment request, and may amend the permit. Prior to issuance of an amended permit, the responsible person must agree in writing that he or she and all of his or her agents will comply with the amended permit and conditions.

(2) *Amendment initiated by APHIS.* The Administrator may amend any

permit and its conditions at any time, upon determining that the amendment is needed to make it unlikely that actions under the permit would result in the introduction or dissemination of a plant pest or noxious weed, or to ensure that the permit is in compliance with all of the requirements of this part. As soon as circumstances allow, the Administrator will notify the responsible person in writing of the amendment to the permit and the reason(s) for it. The responsible person must agree in writing to comply with the permit and conditions as amended before the Administrator will issue the amended permit. If the responsible person does not agree in writing to comply with the amended permit and conditions, the existing permit will be revoked.

(3) *Transfer of permits.* Permits issued through this part may only be transferred by the Administrator in response to a request by both the responsible person and the proposed transferee, or in the case of a deceased responsible person, the deceased responsible person's legal representative and the proposed transferee. Such transfer may occur if the Administrator determines that:

(i) The proposed transferee meets all of the qualifications of a responsible person under this part;

(ii) The proposed transferee has provided adequate written assurances to the Administrator that the proposed transferee and all of his or her agents will meet the terms and conditions of the permit, including any outstanding mitigation requirements or commitments under this part, and that the proposed transferee agrees to assume all responsibility and liability associated with permit activities and responsibilities; and

(iii) The proposed transferee has provided such other information as the Administrator determines is necessary to the processing of the request for transfer of permit.

§ 340.3 Permit conditions.

(a) *Core permit conditions.* Permits will be issued with the permit conditions below, which are a minimum set of basic conditions. The Administrator may add additional or expanded conditions when necessary to make it unlikely that actions under the permit would result in the introduction or dissemination of a plant pest or noxious weed.

(1) *Permit conditions for all permit types.*

(i) *Identity.* The identity of the GE organism shall be maintained at all times, in order to maintain control of the GE organism, keep it distinct from other organisms, and minimize unintended mixing of the GE organism with other organisms. Conditions for maintaining the identity of the GE organism include, but are not limited to:

(A) Marking, labeling, or otherwise identifying all GE organisms during the course of the permit; and

(B) Having the ability to account for all GE materials associated with the permit.

(ii) *Communication and training.* The responsible person shall effectively communicate any and all conditions, activities, actions, and contingency plans associated with the permit to all his or her agents and any other persons participating in permit-related activities, in order to ensure all persons comply with all requirements under this part. Conditions for communicating and training include, but are not limited to:

(A) Establishing, implementing, and maintaining the means to effectively communicate to all his or her agents and any other persons participating in permit-related activities;

(B) Providing a copy of the permit and conditions to all agents involved in a permit; and

(C) Training all agents and any other persons participating in permit-related activities to effectively conduct tasks required under the permit.

(iii) *Records.* In addition to any other records required by this section or § 340.7(b), records, related to permitted activities of sufficient quality and completeness to demonstrate compliance with all permit conditions and requirements under this part, must be maintained.

(iv) *Notice.* The responsible person shall notify APHIS orally within 24 hours of discovery, and subsequently in writing within 5 business days of discovery, in the event of an unauthorized importation, interstate movement, or release into the environment of a GE organism regulated under this part.

(2) Additional permit conditions for interstate movement permits, importation permits, and environmental release permits which include either an interstate movement or importation.

(i) *Shipment.* The GE organism must be transported in such a way as to minimize the likelihood of the unauthorized release of the GE organism. Conditions include, but are not limited to:

(A) Ensuring that the GE organism is transported in such a way that it is a secure shipment, as defined in § 340.1; and

(B) Treating or disposing of all packaging material, shipping containers, and any other material accompanying the GE organism in such a manner as to make it unlikely to result in the organism's unauthorized importation, interstate movement, or release into the environment.

(ii) *Records.* In addition to any other records required by this section or § 340.7(b), the following records shall be maintained:

(A) Information identifying the general nature and quantity of the organism being shipped;

(B) Name and address of sender, owner, or person shipping the organism;

(C) Name, address, and telephone number of recipient;

(D) Any invoices, packing lists, or bills of lading used for the shipment;

(E) The shipper's name and identifying shipper's mark and number; and

(F) A description of any containers that were used to transport the GE organisms, and a copy of any label used on these containers during transport.

(3) *Additional permit conditions for import permits, and environmental release permits which include importation.*

(i) *Port(s) of Entry.* The GE organism shall be presented for entry only at a port(s) specified in the permit.

(ii) *Records.* In addition to any other records required by this section or § 340.7(b), the responsible person shall maintain records that identify the country and locality where the GE organism was collected, developed, manufactured, reared, cultivated or cultured.

(4) *Additional permit conditions for environmental release permits.*

(i) *Environmental release controls.* Sufficient controls shall be applied during the environmental release of the GE organism to make it unlikely to result in the unauthorized release of the GE organism into the environment. Conditions include, but are not limited to:

(A) Taking adequate precautions as described in the permit to ensure that the GE organism is not inadvertently released in transit between contained facilities and the location of environmental release;

(B) Developing and being prepared to implement a written contingency plan to respond to any unauthorized environmental release;

(C) Following any and all required reproductive, cultural, spatial, and temporal controls, such as isolation distances, buffer zones, and flower removal, as described in the permit, and monitor to ensure that the controls are maintained throughout the duration of the release;

(D) Cleaning equipment used in the environmental release in order to remove or devitalize any viable GE organism the equipment may carry, as described in the permit;

(E) Devitalizing or moving into a contained facility any viable GE material remaining at the termination of the environmental release, when applicable, as described in the permit; and

(F) Managing and monitoring the area of release after the termination of the environmental release and removing or devitalizing any GE organisms which persist after the release, as required in the permit.

(ii) *Records.* In addition to any other records required by this section or § 340.7(b), the following records shall be maintained for each release:

(A) All protocols or guidelines used to direct any environmental release of the GE organism; and

(B) All environmental release reports for the organism. At a minimum such reports must include the APHIS reference number for the environmental release, methods of observation used during the environmental release, resulting information, and analysis regarding all deleterious effects on plants, nontarget organisms, or the environment, and any notices sent to APHIS of any unusual occurrence during the environmental release.

(iii) *Reports and Notices.* In order for the Administrator to monitor the progress of the environmental release, and to evaluate compliance with required permit conditions, permit conditions will include, but are not limited to:

(A) The responsible person shall submit periodic reports and notices to APHIS at the times specified in the permit and containing the information specified within the permit; and

(B) The responsible person shall notify APHIS orally within 24 hours of discovery, and subsequently in writing within 5 business days of discovery, in the event that the GE organism is found to have characteristics substantially different from those listed in the permit or if any circumstances occur which may increase the risk of disseminating a plant pest or noxious weed.

(C) The responsible person shall notify APHIS in writing if the authorized release will not be conducted.

(D) Within 28 days after the initiation of the release, the responsible person shall report to APHIS in writing the final release site coordinates; number of GE organisms actually released; any information related to the expected date(s) and quantities of GE organisms for subsequent planned releases to be done under this permit.

(E) The responsible person shall provide APHIS with a final report that includes information related to any occurrences during the release that might result in the dissemination of a plant pest or noxious weed.

(F) For categories C and D, permit holders shall provide APHIS with written notice no less than seven days prior to the planned initiation of the release.

(G) For categories C and D, permit holders shall provide APHIS with a report no less than 21 days prior to release termination (e.g., harvest of GE plants) that describes the anticipated date(s) of termination.

(b) *Standard for additional permit conditions assigned by Administrator.* The Administrator will assign the permit conditions described above in a manner that is commensurate with the risk of the individual proposed release. Additional or expanded permit conditions may include, but are not limited to specific requirements for: Reproductive, cultural, spatial, temporal controls; monitoring; post-termination land use; site security or access restrictions; and management practices such as training of personnel involved in the release. The Administrator may also assign permit conditions addressing nonliving materials associated with or derived from GE plants when such conditions are needed to make it unlikely that the nonliving materials would pose a noxious weed risk.

§ 340.4 Conditional exemptions from the requirement for a permit for interstate movement.

(a) *General.* Certain GE organisms described in paragraph (b) of this section may be moved interstate without a permit under this part, if they meet the shipping conditions enumerated in paragraph (c).

(b) *Conditional exemptions from the requirement for a permit for interstate movement of certain organisms.* A permit for interstate movement will not be required for the following genetically engineered organisms provided that they meet the requirements of this paragraph and paragraph (c).

(1) *Escherichia coli* genotype K–12 (strain K–12 and its derivatives), sterile strains of *Saccharomyces cerevisiae*, or asporogenic strains of *Bacillus subtilis*, provided that the introduced genetic sequences:

(i) Are maintained on a nonconjugation proficient plasmid, and the organism does not contain other conjugation proficient plasmids or generalized transducing phages;

(ii) Do not cause the production of an infectious entity;

(iii) Are not carried on an expression vector if the cloned genes code for:

(*A*) A toxin to plants or plant products, or a toxin to organisms beneficial to plants; or

(*B*) Other factors directly involved in eliciting plant disease (e.g., cell wall degrading enzymes; or

(*C*) Substances acting as, or inhibitory to, plant growth regulators.

(2) *Arabidopsis thaliana* provided that the introduced genetic sequences:

(i) Do not cause the production of an infectious entity;

(*ii*) Are not derived from an animal or human pathogen;

(*iii*) Do not encode products that are toxic to vertebrates;

(*iv*) Do not encode products known to or likely to be causal agents of disease in vertebrates; and

(*v*) Do not encode products intended for pharmaceutical or industrial use.

(c) *Shipping conditions.* Organisms that meet the criteria described in paragraph (b) of this section must be shipped as follows:

(i) The container and means of conveyance must provide secure shipment to make it unlikely that the introduction or dissemination of the organisms will occur while in transit.

(ii) The container must contain a document which includes the following written information:

(A) Names and contact details for the sender and recipient, and

(B) A statement that the contents are genetically engineered and are eligible for interstate movement without permit under this part, but are not exempt from permit requirements under this part if the organism is imported or released into the environment;

(iii) The responsible person shall notify APHIS orally within 24 hours of discovery, and subsequently in writing within 5 business days of discovery, in the event of an unauthorized release into the environment of a GE organism regulated under this part.

(d) *Revocation of an exemption from requirement for permit.* The Administrator may revoke any existing conditional exemption. The Administrator may revoke a conditional exemption if the Administrator receives information subsequent to approving the conditional exemption and makes a determination based upon this information that the circumstances have changed such that the conditional exemption is likely to result in the introduction or dissemination of a plant pest or noxious weed. The revocation, its effective date, and the reasons for it will be published in the **Federal**

Register. A revocation may not be appealed. However, any person may file a new petition in accordance with § 340.5 regarding the same or similar organisms covered by the revocation if new information relevant to the revocation becomes available.

(e) *Revocation of a person's use of a conditional exemption from requirement for permit.* The Administrator may revoke the right of any person to use a conditional exemption from the requirement for a permit under this part after determining that the person or any agent of the person has failed to comply at any time with any provision of this part. This would include failure to comply with the conditions of any permit or exemption.

(1) *Appeal of revocation of a person's use of a conditional exemption.* Any person who has had the right to use a conditional exemption revoked may appeal the decision in writing to the Administrator within ten days after receiving the written notification of the revocation. The appeal shall state all of the facts and reasons upon which the person relies to assert that the use of the conditional exemption was wrongfully revoked. The Administrator will grant or deny the appeal, in writing, stating the reasons for the decision as promptly as circumstances allow. Upon request of the applicant, a hearing may be held to resolve any conflict as to any material fact. Rules of practice concerning such a hearing will be adopted by the Administrator. This administrative remedy must be exhausted before a person can file suit in court challenging the revocation.

§ 340.5 Petition for new conditional exemptions from the requirement for a permit.

(a) *General.* Any person may petition to initiate the procedure for establishing a new conditional exemption from the requirement for a permit under § 340.0(b)(1) of this part. The Administrator may initiate the procedure without filing a petition. All petitions and all actions by the Administrator to establish a new conditional exemption will be evaluated according to the standards for petition approval or denial contained in paragraph (b)(4) of this section.

(b) *Petition submission and evaluation procedure.* To petition for a new conditional exemption from the requirement for a permit under this part, a petitioner must submit a written petition to the Administrator.

(1) The petition must contain information that supports a conclusion that use of the conditional exemption is unlikely to result in the introduction or dissemination of a plant pest or noxious weed. The information shall include the following:

(i) Description of the biology of the organism prior to genetic engineering.

(ii) Detailed description of the genetic changes made to the organism.

(iii) Detailed description of the phenotype of the GE organism, including known and potential differences from the recipient organism that could change the likelihood that the GE organism will pose a risk as a plant pest or noxious weed. Examples of relevant information include, but are not limited to:

(A) Growth habit and reproduction of the GE organism;

(B) Potential host range or geographic area of distribution;

(C) Potential for other organisms to pose risks as plant pests or noxious weeds if they acquire the trait from the GE organism (e.g. via sexual reproduction, horizontal gene transfer);

(D) Susceptibility of the GE organism to disease or damage by pests;

(E) Pathogenicity of the GE organism and/or ability of the GE organism to cause damage or injury to plants or plant parts;

(F) Toxicity, allergenicity, and/or ability of the GE organism to damage or injure other organisms;

(iv) A detailed description of proposed condition(s) to be associated with the exemption and how the conditions would make the exemption unlikely to result in the introduction or dissemination of a plant pest or noxious weed.

(v) Any relevant experimental information, published references, or scientific information which support the conclusions of the petition;

(vi) All reports required under § 340.3;

(vi) Any information known to the petitioner that the GE organism may pose a risk as a plant pest or noxious weed;

(vii) Any other information that the Administrator believes to be relevant to a determination that the proposed conditional exemption from the requirement for a permit for the importation, interstate movement, or release into the environment of the GE organism is unlikely to result in the introduction or dissemination of a plant pest or noxious weed.

(viii) A signed certification by the petitioner that, to the best knowledge and belief of the petitioner, the petition includes all information on which to base a determination, and that it includes all information known to the petitioner which is unfavorable to the petition.

(2) *Insufficient information.* If, upon initial review of the petition, the Administrator concludes that there is insufficient information upon which to make a determination on the petition, the petitioner will be sent a written notice indicating what additional information may be required.

(3) *Public notice.* The Administrator should generally complete the review of the complete petition within 180 days, then publish a notice in the **Federal Register** of the availability of documents related to APHIS' assessment of the proposed conditional exemption. This notice will specify that comments will be accepted from the public on the proposal.

(4) *Petition approval or denial standard.* The Administrator will assess the GE organism and the conditions of the requested exemption to determine whether the requested exemption from a permit for importation, interstate movement, or release into the environment would be unlikely to result in the introduction or dissemination of a plant pest or noxious weed. The Administrator will also consider whether any conditions not contained in the petition would be needed to ensure that the requested exemption would be unlikely to result in the introduction or dissemination of a plant pest or noxious weed. After completing review of the available information and any public comments received on it, the Administrator will furnish to the petitioner and publish in the **Federal Register** one of the following responses:

(i) *Approve a conditional exemption from requirement for a permit.* The approval of a conditional exemption from the requirement for a permit will state which GE organism(s) may be imported, moved interstate, and/or environmentally released without a permit under this part, as well as the conditions relevant to the exemption. The Administrator may also add additional conditions not proposed in the petition, if the Administrator concludes that additional conditions are needed to ensure that the conditional exemption would be unlikely to result in the introduction or dissemination of a plant pest or noxious weed.

(ii) *Deny a conditional exemption from requirement for a permit.* The Administrator will deny a petition if the Administrator cannot conclude that the proposed exemption would be unlikely to result in the introduction or dissemination of a plant pest or noxious weed. The Administrator's written decision will set forth the reason for the denial.

(c) *Appeal of decision.* Any person whose petition under § 340.5 has been denied may appeal the decision in writing to the Administrator within ten days after receiving the written notification of the decision. The appeal shall state all of the facts and reasons upon which the person relies to show that the decision should be changed. The Administrator will grant or deny the appeal, in writing, stating the reasons for the decision as promptly as circumstances allow. Upon request of the applicant, a hearing may be held to resolve any conflict as to any material fact. Rules of practice concerning such a hearing will be adopted by the Administrator. This administrative remedy must be exhausted before a person can file suit in court challenging the decision.

(d) *Amending an exemption after approval.* The Administrator may amend conditions to any conditional exemption approved under this section. The Administrator may amend a conditional exemption if the Administrator determines based on information received subsequent to the approval of the exemption that the exemption needs to be amended to ensure that the exemption would be unlikely to result in the introduction or dissemination of a plant pest or noxious weed, and that additional conditions can successfully mitigate that risk. The Administrator may also amend a conditional exemption if needed to ensure that the exemption is in compliance with all of the requirements of this part. The amended conditional exemption and the reasons for it will be published in the **Federal Register**. The addition of conditions may not be appealed. However, any person may file a new petition in accordance with paragraph (a) of this section regarding the same or similar organisms covered by the amended exemption if new information relevant to the amended exemption becomes available.

(e) *Revocation of an exemption from requirement for permit.* The Administrator may revoke any conditional exemption under this section. The Administrator may revoke a conditional exemption if the Administrator receives information subsequent to approving the exemption and makes a determination based upon this information that the circumstances have changed such that the conditional exemption is likely to result in the introduction or dissemination of a plant pest or noxious weed. The revocation, its effective date, and the reasons for it will be published in the **Federal Register**. A revocation may not be appealed. However, any person may file a new petition in accordance with this section regarding the same or similar organisms covered by the revocation if new information relevant to the revocation becomes available.

(f) *Revocation of a person's use of a conditional exemption from requirement for permit.* The Administrator may revoke the right of any person to use a conditional exemption from the requirement for a permit under this part after determining that the person or any agent of the person has failed to comply at any time with any provision of this part. This would include failure to comply with the conditions of any permit or exemption.

(1) *Appeal of revocation of a person's use of a conditional exemption.* Any person who has had the right to use a conditional exemption revoked may appeal the decision in writing to the Administrator within ten days after receiving the written notification of the revocation. The appeal shall state all of the facts and reasons upon which the person relies to assert that the use of the exemption was wrongfully revoked. The Administrator will grant or deny the appeal, in writing, stating the reasons for the decision as promptly as circumstances allow. Upon request of the applicant, a hearing may be held to resolve any conflict as to any material fact. Rules of practice concerning such a hearing will be adopted by the Administrator. This administrative remedy must be exhausted before a person can file suit in court challenging the revocation.

(2) [Reserved]

§ 340.6 Petition for nonregulated status.

(a) *General.* Any person may petition to initiate the procedure for approving nonregulated status under this part for a GE organism. The Administrator may initiate the procedure without filing a petition. All petitions and all actions by the Administrator to initiate the procedure for approving nonregulated status will be evaluated according to the standards for petition approval or denial contained in paragraph (b)(4) of this section.

(b) *Petition submission and evaluation procedure.* To petition for approval of nonregulated status, a petitioner must submit a written petition to the Administrator.

(1) The petition must contain information that supports a conclusion that the GE organism is unlikely to be a plant pest or noxious weed. The information shall include the following:

(i) Description of the biology of the organism prior to genetic engineering.

(ii) Detailed description of the genetic changes made to the organism.

(iii) Detailed description of the phenotype of the GE organism, including known and potential differences from the recipient organism that could change the likelihood that the GE organism is unlikely to be a plant pest or noxious weed. Examples of relevant information include, but are not limited to:

(A) Growth habit and reproduction of the GE organism;

(B) Potential host range or geographic area of distribution;

(C) Potential for other organisms to pose risks as plant pests or noxious weeds if they acquire the trait from the GE organism (e.g. via sexual reproduction, horizontal gene transfer);

(D) Susceptibility of the GE organism to disease or damage by pests;

(E) Pathogenicity of the GE organism and/or ability of the GE organism to cause damage or injury to plants or plant parts;

(F) Toxicity, allergenicity, and/or ability of the GE organism to damage or injure other organisms;

(iv) Any relevant experimental information, published references, or scientific information which support the conclusions of the petition;

(v) All reports required under § 340.3;

(vi) Any information known to the petitioner that the GE organism may pose risk as a plant pest or noxious weed;

(vii) Any other information that the Administrator believes to be relevant to a determination that the GE organism is unlikely to be a plant pest or noxious weed.

(viii) A signed certification by the petitioner that, to the best knowledge and belief of the petitioner, the petition includes all information on which to base a determination, and that it includes all information known to the petitioner which is unfavorable to the petition.

(2) *Insufficient information.* If, upon initial review of the petition, the Administrator concludes that there is insufficient information upon which to make a determination on the petition, the petitioner will be sent a written notice indicating what additional information may be required.

(3) *Public notice.* The Administrator should generally complete the review of the complete petition within 180 days, then publish a notice in the **Federal Register** of the availability of documents related to APHIS' assessment of the proposal for nonregulated status. This notice will specify that comments will be accepted from the public on the proposal.

(4) *Petition approval or denial standard.* The Administrator will assess the GE organism to determine whether the GE organism is unlikely to be a plant pest or noxious weed. After completing review of the available information and any public comments received on it, the Administrator will furnish to the petitioner and publish in the **Federal Register** one of the following responses:

(i) *Approve nonregulated status.* The approval of nonregulated status will state which GE organism(s) have been determined to have nonregulated status.

(ii) *Deny nonregulated status.* The Administrator will deny a petition if the Administrator cannot conclude that the GE organism is unlikely to be a plant pest or noxious weed. The Administrator's written decision will set forth the reason for the denial.

(c) *Appeal of decision.* Any person whose petition under § 340.6 has been denied may appeal the decision in writing to the Administrator within ten days after receiving the written notification of the decision. The appeal shall state all of the facts and reasons upon which the person relies to show that the decision should be changed. The Administrator will grant or deny the appeal, in writing, stating the reasons for the decision as promptly as circumstances allow. Upon request of the applicant, a hearing may be held to resolve any conflict as to any material fact. Rules of practice concerning such a hearing will be adopted by the Administrator. This administrative remedy must be exhausted before a person can file suit in court challenging the decision.

(d) *Revocation of nonregulated status.* The Administrator may revoke any approval of nonregulated status of a GE organism. The Administrator may revoke an approval of nonregulated status if the Administrator receives information subsequent to approving the nonregulated status and makes a determination based upon this information that the circumstances have changed such that the GE organism is likely to be a plant pest or noxious weed. If the Administrator revokes an approval for nonregulated status, the Administrator may approve for the same GE organism an exemption from the requirement for permit in accordance with § 340.5. The revocation, its effective date, and the reasons for it will be published in the **Federal Register**. A revocation may not be appealed. However, any person may file a new petition in accordance with this section regarding the same or similar organisms covered by the revocation if new information relevant to the revocation becomes available.

§ 340.7 Compliance, enforcement, and remedial action.

(a) *Access for inspection.* Inspectors shall have access to inspect any relevant premises, facility, location, storage area, waypoint, materials, equipment, means of conveyance, and other articles related to importation, interstate movement, and environmental releases of GE organisms regulated under this part.

(b) *Access to audit and review records.* Inspectors shall have access to audit and review all records required to be maintained under this part.

(c) *Required records.* Responsible persons and their agents engaged in the importation, interstate movement, or release into the environment of a GE organism subject to the regulations of this part are required to establish and keep the following records.

(1) All records required as a condition of a permit or a conditional exemption approved under the procedure described in § 340.5.

(2) Address and any other information needed to identify all contained facilities where the GE organism was stored or utilized, and all locations where the GE organism was released into the environment;

(3) A record identifying which APHIS permit, if any, authorized the importation, interstate movement, or release into the environment;

(4) A record identifying which exemption under this part, if any, authorized the importation, interstate movement, or release into the environment; and

(5) Copies of contracts between the responsible person and all agents that conduct activities subject to this part for the responsible person, and copies of other records (e.g., e-mails, telephone records) for such agreements made without a written contract.

(d) *Record retention.* Records indicating that such a GE organism that was imported or moved interstate reached its intended destination must be retained for at least 2 years after completion of importation or interstate movement, and all other records must be retained for at least 5 years after completion of all obligations required under a relevant permit or exemption.

(e) *Enforcement.* (1) Failure of any person to comply with any of the requirements of this part may result in any or all of the following:

(i) Denial of a permit request by that person;

(ii) After the issuance of a permit, revocation of a permit and destruction, treatment, or removal of the GE organism, or other measures as deemed appropriate or necessary by the Administrator;

(iii) Criminal and/or civil penalties, and

(iv) Remedial or other measures as determined appropriate and necessary by the Administrator.

(2) The Administrator may seek a civil penalty as well as impose and require corrective action plans, remedial measures or other measures as determined appropriate and necessary by the Administrator.

(3) Prior to the issuance of a complaint seeking a civil penalty, the Administrator may enter into a stipulation in which the responsible person agrees to take certain remedial actions or other measures in addition to or in lieu of a stipulated civil penalty, in accordance with 7 CFR § 380.10.

(f) *Liability for acts of an agent.* For purposes of enforcing this part, the act, omission, or failure of any agent for a responsible person as defined in § 340.1 of this part may be deemed also to be the act, omission, or failure of the responsible person.

(g) *Remedial action.* The Administrator may hold, seize, quarantine, treat, apply other remedial measures to, destroy, or otherwise dispose of any GE organisms subject to this part, in order to ensure the GE organisms are unlikely to result in the dissemination of a plant pest or noxious weed. Accordingly, the Administrator may order the responsible person for an active or revoked permit or any other person, through an Emergency Action Notification or other administrative order, to apply remedial measures to a GE organism or means of conveyance carrying a GE organism subject to regulation by this part. The Administrator's determination of whether or not to require or order corrective and/or remedial action in a given situation does not affect, influence, restrict, or in any other way limit the Administrator's determination on whether or not to seek criminal or civil penalties or order other compliance or enforcement requirements as deemed necessary or appropriate by the Administrator to the given situation.

(1) Failure of a person to comply with the Administrator's order for corrective and/or remedial action authorizes the Administrator to take corrective and/or remedial action and recover from the person the costs of any care, handling, application of remedial measures, devitalization, or disposal incurred by APHIS in connection with the corrective and/or remedial actions taken.

(2) *Low level presence (LLP) remedial action.* The Administrator may order remedial action for any unauthorized release into the environment of GE

organisms, including situations involving a low-level mixing of GE plants and materials subject to regulation [1] under this part with commercial seed and grain. In some LLP situations the Administrator may determine not to order remedial action, if the Administrator determines that the low-level mixing is unlikely to result in the introduction or dissemination of a plant pest or noxious weed. These determinations will be made in the same way, based on the same factors, regardless of whether the LLP originates domestically or is found in import shipments that may contain organisms subject to regulation. The factors the Administrator will consider that would support a decision not to order LLP remedial action include, but are not limited to, determinations that:

(i) A GE plant of the same species expressing nearly identical proteins or substances has already been approved for nonregulated status under this part; or

(ii) All of the following statements are true with regard to the GE plant or plants subject to the regulations under this part.

(A) The function of the introduced genetic sequences is known and its expression in the GE plant is unlikely to pose plant pest or noxious weed risk;

(B) Introduced genetic sequences do not cause the production of an infectious entity;

(C) Any genetic sequences derived from plant viruses are non-coding regulatory sequences of known function; or, if sense or antisense genetic sequences, they are derived from viruses prevalent and endemic in the United States that infect plants of the same host species and do not encode a functional noncapsid gene product responsible for cell-to-cell movement of the virus.

(D) The GE plant is not expected to establish outside of a managed ecosystem, and has no sexually-compatible, wild relatives in the United States;

(E) The GE plant does not produce new substances that are known or likely to be toxic to non-target organisms, does not contain genetic sequences from animal or human pathogens, and does not encode products known or likely to be causal agents of disease in animals or humans.

(F) If the GE plant is a food or feed crop, then at least one of the following must be true:

(*1*) The U.S. Environmental Protection Agency has established a tolerance or an exemption from tolerance for any plant-incorporated protectant expressed by the GE plant, or

(*2*) Key food safety issues of the new protein or other substance have been addressed, or,

(*3*) No new protein or substance is produced.

§ 340.8 Confidential business information.

In accordance with the Freedom of Information Act (FOIA) and exemptions from releasing information pursuant to FOIA, namely, 5 U.S.C. 552(b)(4), APHIS may exempt from disclosure to the public trade secrets and commercial or financial information obtained from a person that are privileged or confidential. Persons wishing to protect confidential business information in permit applications, petitions, or other submissions to APHIS under this part should do so in the following manner. If there are portions of a document deemed to contain trade secret or confidential business information, each page containing such information must be marked "CBI Copy." A second copy of each such document must be submitted with all such CBI deleted and marked on each page where the CBI was deleted: "CBI Deleted." In addition, those portions of the document which are deemed "CBI" must be identified in an attachment to the document, which also must justify how each piece of information requested to be treated as CBI is a trade secret or is commercial or financial information and are privileged or confidential.

§ 340.9 Costs and charges.

The services of the inspector related to carrying out this part and provided during regularly assigned hours of duty and at the usual places of duty will be furnished without cost.[2] The U.S. Department of Agriculture will not be responsible for any costs or charges incident to inspections or compliance with the provisions of this part, other than for the services of the inspector.

Done in Washington, DC, this 1st day of October 2008.

Charles D. Lambert,

Acting Under Secretary for Marketing and Regulatory Programs.

[FR Doc. E8–23584 Filed 10–6–08; 9:30 am]

BILLING CODE 3410–34–P

[1] "Subject to regulation" may include situations where a GE organism granted nonregulated status subsequently had that status revoked in accordance with § 340.6(d).

[2] The Department's provisions relating to overtime charges for an inspector's services are set forth in 7 CFR part 354.0.

Regulatory Analysis and Development, PPD, APHIS, Station 3A–03.8, 4700 River Road Unit 118, Riverdale, MD 20737–1238. Please state that your comment refers to Docket No. APHIS–2008–0098.

Reading Room: You may read any comments that we receive on this docket in our reading room. The reading room is located in room 1141 of the USDA South Building, 14th Street and Independence Avenue SW., Washington, DC. Normal reading room hours are 8 a.m. to 4:30 p.m., Monday through Friday, except holidays. To be sure someone is there to help you, please call (202) 690–2817 before coming.

Other Information: Additional information about APHIS and its programs is available on the Internet at *http://www.aphis.usda.gov.*

FOR FURTHER INFORMATION CONTACT: Dr. Edward Jhee, Biotechnology Quality Management System Program Manager, Biotechnology Regulatory Services, APHIS, 4700 River Road Unit 91, Riverdale, MD 20737–1236; (301) 734–6356, *edward.m.jhee@aphis.usda.gov.* To obtain copies of the draft audit standard, contact Ms. Cindy Eck at (301) 734–0667, e-mail: *cynthia.a.eck@aphis.usda.gov.* The draft audit standard is also available on the Internet at *http://www.aphis.usda.gov/biotechnology/news_bqms.shtml.*

SUPPLEMENTARY INFORMATION:

Background

The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) regulates the introduction—meaning the importation, interstate movement, and environmental release—of genetically engineered (GE) organisms that are, or may be, plant pests. Such GE organisms and products are considered "regulated articles." Applicants that are issued permits or received acknowledgment of notifications to introduce GE organisms are required to comply with all APHIS regulations.

To enhance improvements in compliance, APHIS initiated development of a voluntary, audit-based compliance assistance program known as the Biotechnology Quality Management System (BQMS). On September 20, 2007, APHIS issued a press release announcing plans to establish a BQMS Pilot Development Project.

APHIS selected five volunteer participants for the pilot program after soliciting letters of interest through a notice published in the **Federal Register** on September 2, 2008 (73 FR 51266–51267, Docket No. APHIS–2008–0098). The main component of the BQMS pilot project is the draft audit standard, which provides criteria used for the objective evaluation of quality management systems to determine if a system will be certified as an APHIS Biotechnology Quality Management System during the audit portion of the pilot program. The regulatory requirements of 7 CFR part 340 for performance standards and permit conditions are the foundation for the draft audit standard.

The draft audit standard is used by pilot participants to develop sound management practices to enhance compliance with the regulatory requirements of 7 CFR part 340 for environmental releases, importations, and interstate movements of regulated articles. Participants have applied the draft audit standard to their organization's regulated biotechnology program to plan, implement, document, and examine the efficacy of quality assurance and quality control measures related to introductions of regulated articles.

APHIS is soliciting comments for a period of 60 days on the draft audit standard currently used in the BQMS pilot project. Within the draft audit standard, Requirement 7 specifies that participants address critical control points for the introduction of regulated articles by developing containment procedures for regulated articles; developing measures for the identification of regulated articles in storage, being moved, imported, or transferred, and in field locations; developing procedures for planning and monitoring environmental releases of regulated articles; developing methods for post-harvest handling activities and methods to maintain the identity of regulated material; developing procedures for the devitalization and disposition of regulated articles; as well as developing procedures for the submission of regulatory compliance incidents to the appropriate regulatory authorities. APHIS is soliciting comments on the draft audit standard as a whole, and Requirement 7 in particular.

1. Do the critical control points in Requirement 7 of the draft audit standard identify all areas and elements that organizations should focus on in order to maintain compliance with the regulatory requirements under 7 CFR part 340?

2. Is the draft audit standard consistent with current best practices used by the regulated community?

3. Can the public identify incentives USDA might employ to encourage participation in the voluntary program by commercial industry as well as academic institutions?

4. The BQMS is designed to be flexible according to the size of the participating organization. Is this flexibility apparent in the draft audit standard?

Upon conclusion of the BQMS pilot project, APHIS will consider all comments received during the comment period to revise the draft audit standard to improve the efficacy of this project. This feedback, as well as comments from the participants on the pilot BQMS project, will be used to inform the development of a BQMS audit standard and any future BQMS initiative. The BQMS draft audit standard is available for public review as indicated under the **ADDRESSES** and **FOR FURTHER INFORMATION CONTACT** sections of this notice.

Done in Washington, DC, this 29th day of May 2009.

Kevin Shea,

Acting Administrator, Animal and Plant Health Inspection Service.

[FR Doc. E9–13053 Filed 6–3–09; 8:45 am]

BILLING CODE 3410–34–P

DEPARTMENT OF AGRICULTURE

Animal and Plant Health Inspection Service

[Docket No. APHIS–2007–0016]

Syngenta Seeds, Inc.; Availability of Petition and Environmental Assessment for Determination of Nonregulated Status for Corn Genetically Engineered To Produce an Enzyme That Facilitates Ethanol Production

AGENCY: Animal and Plant Health Inspection Service, USDA.

ACTION: Notice; reopening of comment period.

SUMMARY: We are reopening the comment period for a petition submitted by Syngenta Seeds, Inc., seeking a determination of nonregulated status for corn designated as transformation event 3272 and its associated environmental assessment prepared by the Animal and Plant Health Inspection Service under our regulations found at 7 CFR part 340. This action will allow interested persons additional time to prepare and submit comments on the petition, environmental assessment, and the revised plant pest risk assessment.

DATES: We will consider all comments that we receive on or before July 6, 2009.

ADDRESSES: You may submit comments by either of the following methods:

- *Federal eRulemaking Portal:* Go to *http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d=APHIS-2007-0016* to submit or view comments and to view supporting and related materials available electronically.
- *Postal Mail/Commercial Delivery:* Please send two copies of your comment to Docket No. APHIS-2007-0016, Regulatory Analysis and Development, PPD, APHIS, Station 3A03.8, 4700 River Road Unit 118, Riverdale, MD 20737-1238. Please state that your comment refers to Docket No. APHIS-2007-0016.

Reading Room: You may read any comments that we receive on this docket in our reading room. The reading room is located in room 1141 of the USDA South Building, 14th Street and Independence Avenue SW., Washington, DC. Normal reading room hours are 8 a.m. to 4:30 p.m., Monday through Friday, except holidays. To be sure someone is there to help you, please call (202) 690-2817 before coming.

Other Information: Additional information about APHIS and its programs is available on the Internet at *http://www.aphis.usda.gov.*

FOR FURTHER INFORMATION CONTACT: Dr. Andrea Huberty, Biotechnology Regulatory Services, APHIS, 4700 River Road Unit 146, Riverdale, MD 20737-1236; (301) 734-0485, e-mail: *andrea.f.huberty@aphis.usda.gov.* To obtain copies of the petition, the draft environmental assessment, or the plant pest risk assessment, contact Ms. Cindy Eck at (301) 734-0667, e-mail: *cynthia.a.eck@aphis.usda.gov.* The petition, draft environmental assessment, and plant pest risk assessment are also available on the Internet at *http://www.aphis.usda.gov/brs/aphisdocs/05_28001p.pdf, http://www.aphis.usda.gov/brs/aphisdocs/05_28001p_ea.pdf,* and *http://www.aphis.usda.gov/brs/aphisdocs/05_28001p_ra.pdf.*

SUPPLEMENTARY INFORMATION: The regulations in 7 CFR part 340, "Introduction of Organisms and Products Altered or Produced Through Genetic Engineering Which Are Plant Pests or Which There Is Reason to Believe Are Plant Pests," regulate, among other things, the introduction (importation, interstate movement, or release into the environment) of organisms and products altered or produced through genetic engineering that are plant pests or that there is reason to believe may be plant pests. Such genetically engineered (GE) organisms and products are considered "regulated articles."

On October 7, 2005, APHIS received a petition seeking a determination of nonregulated status (APHIS Petition No. 05-280-01p) from Syngenta Seeds, Inc., of Research Triangle Park, NC (Syngenta), for corn (*Zea mays* L.) designated as transformation event 3272, which has been genetically engineered to produce a microbial enzyme that facilitates ethanol production. The petition stated that Event 3272 corn is unlikely to pose a plant pest risk and, therefore, should not be a regulated article under APHIS' regulations in 7 CFR part 340.

In a notice[1] published in the **Federal Register** on November 19, 2008 (73 FR 69602-69604, Docket No. APHIS-2007-0016), APHIS announced the availability of the Syngenta petition and a draft environmental assessment (EA) for public comment. APHIS solicited comments on the petition, whether the subject corn is likely to pose a plant pest risk, and on the draft EA. APHIS received over 13,000 comments on the petition, the draft EA, and the plant pest risk assessment by the close of the 60-day comment period, which ended on January 20, 2009.

There were 40 comments from organizations or individuals that supported the deregulation of the Event 3272 corn. Over 13,000 comments opposed to the deregulation were submitted. The vast majority of the approximately 13,000 comments opposing the deregulation were from letters conveying essentially identical points compiled by organizations generally opposed to any genetic engineering of plants. Several individuals and organizations also submitted documents, many popular press articles or documents published by those opposed to genetic engineering of plants in general, which they assert are relevant to this regulatory decision for Event 3272 corn.

Most of the comments supporting nonregulated status for Event 3272 corn came from organizations representing corn farmers and ethanol production interests. These comments include statewide corn growers' and agribusiness associations from at least 12 different States where most of the nation's corn is grown. Several national organizations also voiced their support for the deregulation. The principal reasons given by these groups are the benefits anticipated for farmers and the ethanol production industry, as well as the ability to meet biofuel production mandates and to promote international trading interests. While APHIS does not determine nonregulated status for GE organisms pursuant to its biotech regulations (Part 340) based on economic or marketing factors, the support from farmers of corn does suggest that individuals with a substantial interest in the health of the national corn crop do not perceive that either plant pest risks or economic/marketing risks will arise if Event 3272 corn is granted nonregulated status.

Several of the comments provided scientific support for the deregulation of Event 3272 corn. Many of these supportive statements were based on scientific studies included in the petition (such as evidence of decreased water use in ethanol production, reduced greenhouse gas emissions, other reduced inputs in ethanol production). There were several comments that also provided additional studies that would support deregulation of Event 3272 corn on the basis of diminished environmental impacts compared to current ethanol production practices. These studies supported the findings of lowered greenhouse gas emissions and reduced inputs, and also suggest that there will be no impacts on wet distilled grains and improved dried distilled grains, and that the Event 3272 corn is equivalent to currently grown corn lines in other agronomic and nutritional qualities, demonstrated through field and feed studies.

Many of the comments that opposed deregulation were based on general opposition to the development and use of GE plants, without citing or addressing any specific environmental issues in the EA or the pest risk assessment for the petition for Event 3272 corn. Many of these comments simply assert that APHIS should prepare an Environmental Impact Statement to fully address all the potential issues associated with a decision to grant nonregulated status to Event 3272 corn without specifically explaining what they perceive to be the inadequacies of the draft EA's environmental analysis. There were many general comments expressing generic, nonspecific concerns over possible gene flow, disruption to organic farming practices, and concerns of food and environmental safety.

Another common comment that APHIS received regarding the determination of nonregulated status for Event 3272 corn is the general "energy" concern related to the effectiveness and value of producing ethanol from corn. Many comments suggested that

[1] To view the notice, petition, draft EA, the plant pest risk assessment and the comments we received, go to *http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d=APHIS-2007-0016.*

producing ethanol from corn is not an efficient method for achieving energy needs or meeting any alternative energy mandates for the United States. However, in determining the nonregulated status for a genetically engineered plant pursuant to its Part 340 biotechnology regulations, APHIS does not have authority to consider the economic, marketing, or commercial usefulness of the plant, or issues such as the feasibility of meeting energy needs through any particular crop and its related harvesting and processing aspects.

APHIS did receive some comments that raised specific issues of concern if Event 3272 corn was granted nonregulated status. These issues included specific food safety concerns such as the potential for Event 3272 corn to be allergenic, as well as concerns surrounding the potential economic and manufacturing issues if Event 3272 corn were to become present in corn wet-milling processes.

APHIS does believe it is appropriate to address in this notice certain comments submitted that questioned the conclusion that Event 3272 corn is not a plant pest, and that there is no basis for regulatory control of this GE plant under our statutory authorities and Part 340 biotechnology regulations. These comments argue that the alpha-amylase enzyme engineered into Event 3272 corn may cause damage (degradation of corn starch products) to manufactured or processed plant products if Event 3272 corn is included in the manufacturing and processing of corn starch products. The comments claim that this type of damage comes within the definition of a plant pest. One of these comments [2] claims that "a plant pest consists of any living stage of an article similar to or allied with a bacterium or any article similar to or allied with a bacterium that can cause direct damage to a processed plant product. The 'article' in this application (petition) is the thermo-stable alpha-amylase enzyme expressed in Event 3272, which has the potential for injury to plant products if misdirected to corn wet milling facilities.

APHIS' statutory authority to regulate genetically engineered organisms under the Plant Protection Act (PPA) (7 U.S.C. 7701 *et seq.*) and its Part 340 biotechnology regulations is limited to those GE organisms that are plant pests as defined in Section 403, Subsection 14 of the PPA:

> Plant Pest—The term "plant pest" means any living stage of any of the following that can directly or indirectly injure, cause damage to, or cause disease in any plant or plant product:
> (A) A protozoan.
> (B) A nonhuman animal.
> (C) A parasitic plant.
> (D) A bacterium.
> (E) A fungus.
> (F) A virus or viroid.
> (G) An infectious agent or other pathogen.
> (H) Any article similar to or allied with any of the articles specified in the preceding subparagraphs.

Thus, in regulating GE organisms under 7 CFR part 340, APHIS takes a "safeguarding" approach and examines the plant pest risk for genetically engineered plants by looking at all regulated genetically engineered plants for their potential to be plant pests (See plant pest risk assessment, pg. 1). However, under its PPA statutory authorities APHIS cannot regulate GE plants that are outside the PPA's plant pest definition in 7 U.S.C. 7702(14). This statutory definition provides specifically that only a parasitic plant can be a plant pest.

One of the central purposes of the PPA is to prevent the introduction into or dissemination of plant pests within the United States. The PPA at 7 U.S.C. 7702(14) provides that a plant pest must be a living stage of one of a specific list of organisms ("articles") that cause injury, damage, or disease in plants or plant products, or an article similar to or allied with such an organism (article). An "article" is defined in the PPA (7 U.S.C. 7702(1) as follows:

> Article—The term 'article' means any material or tangible object that could harbor plant pests or noxious weeds.

As mentioned above, there were some comments that questioned the conclusion that Event 3272 corn is not a plant pest. These comments argue that the alpha-amylase enzyme in Event 3272 corn is a plant pest because it may interfere with corn starch processing and thus directly or indirectly damage plants or plant products. The developer of Event 3272 corn submitted a document after the close of the document [3] period that argues that Event 3272 corn does not meet the PPA statutory definition of a plant pest. In this document, the commenter provided its analysis of APHIS' regulatory authority under the PPA, and among other things, suggests that separate constituent parts of an organism (in this case, an enzyme expressed by Event 3272 corn) are excluded from the definition of plant pest in the PPA because the enzyme "cannot be regarded as 'living'."

APHIS agrees that enzymes such as alpha-amylase are proteins that catalyze chemical reactions. Enzymes are not "living." Thus, enzymes cannot be plant pests because they are not living and cannot be a "living stage" of any of the organisms ("articles") listed in the PPA's definition of a plant pest in subparagraphs (A) through (G) of 7 U.S.C. 7702(14). Likewise, the Event 3272 corn alpha-amylase enzyme also cannot be a living stage of any article similar to or allied with any of the articles specified in subparagraphs (A) through (G), and thus does not fall within the statutory definition of a plant pest as listed in subparagraph (H) of the PPA's plant pest definition (*i.e.*, "Any article similar to or allied with any of the articles specified in the preceding subparagraphs"). APHIS has determined that the alpha-amylase enzyme engineered into Event 3272 corn is not a plant pest because the alpha-amylase enzyme in Event 3272 corn is not living and thus cannot itself be a living stage of any organism listed in the PPA's plant pest definition.

Moreover, Event 3272 corn itself is not a plant pest since it is clearly not a living stage of any of the organisms (articles) listed in subparagraphs (A) through (G) of 7 U.S.C. 7702(14). Nor is Event 3272 corn itself the living stage of any article (organism) similar to or allied with any of the articles specified in subparagraphs (A) through (G) as required by subparagraph (H) of 7 U.S.C. 7702(14). Thus, APHIS has likewise determined that Event 3272 corn itself is not a plant pest as defined by the PPA. Nevertheless, APHIS evaluated the ability of Event 3272 corn to harbor plant pests in the Plant Pest Risk Assessment and determined that Event 3272 corn does not harbor any living stage of any of the organisms (articles) that are defined as potential plant pests in subparagraphs (A) through (G). First, APHIS described the genetic material that was inserted into Event 3272 corn, which included sequences from plant pests, and included an assessment analyzing the plant disease risk posed by the genetic sequences. Second, APHIS also analyzed the risk that Event 3272 corn would disseminate plant pests (*i.e.* act as an 'article'). APHIS concluded that the inserted genetic material in Event 3272 corn does not cause plant disease and Event 3272 corn does not increase susceptibility to plant disease or insect pests, and therefore does not harbor plant pests. (The comments received on the docket

[2] *See http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=APHIS-2007-0016-0175.1.*

[3] *See http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=APHIS-2007-0016-0222.1.*

during the initial comment period did not dispute or comment on these particular issues related to APHIS' plant pest risk assessment.)

For the reasons explained above, APHIS has determined that neither Event 3272 corn itself, nor the alpha-amylase enzyme in Event 3272 corn, is a plant pest. To make clear APHIS' above determination that neither Event 3272 corn, nor the alpha-amylase enzyme in Event 3272 corn, is a "living stage" of any of the organisms (articles) listed in subparagraphs (A) through (H) of the PPA's plant pest definition, APHIS has revised the plant pest risk assessment for Event 3272 corn to include the PPA's definition of a plant pest. The revised assessment also concludes that neither Event 3272 corn nor the alpha-amylase enzyme in Event 3272 corn is a plant pest because neither Event 3272 corn nor the alpha-amylase enzyme meets the PPA's definition of a plant pest. These revisions to the plant pest risk assessment are for clarity and further explanation, but do not change the overall conclusions made in the draft plant pest risk assessment that Event 3272 corn is unlikely to pose a plant pest risk.

APHIS welcomes additional comment on the issues raised during this process. APHIS is also requesting comment on the revised plant pest risk assessment, and APHIS' conclusion, as explained above, that Event 3272 corn and the alpha-amylase enzyme in Event 3272 corn are not plant pests. APHIS will carefully evaluate all additional comments received during this process, and any other relevant information. All comments received regarding the petition, draft EA, and plant pest risk assessment will be available for public review on the Regulations.gov Web site (see footnote 1 for a link). After reviewing and evaluating the comments on the petition, draft EA, plant pest risk assessment, and other relevant information, APHIS will make its determination, either approving or denying the petition. APHIS will then publish a notice in the **Federal Register** announcing the regulatory status of Event 3272 corn and the availability of APHIS' written regulatory and environmental decision.

Accordingly, we are reopening the comment period on Docket No. APHIS–2007–0016 for an additional 30 days. This action will allow interested persons additional time to prepare and submit comments. We will also consider all comments received between January 21, 2009 (the day after the close of the original comment period), and the date of this notice.

Authority: 7 U.S.C. 7701–7772 and 7781–7786; 31 U.S.C. 9701; 7 CFR 2.22, 2.80, and 371.3.

Done in Washington, DC, this 29th day of May 2009.

Kevin Shea,

Acting Administrator, Animal and Plant Health Inspection Service.

[FR Doc. E9–13055 Filed 6–3–09; 8:45 am]

BILLING CODE 3410–34–P

DEPARTMENT OF AGRICULTURE

Rural Utilities Service

PowerSouth Energy Cooperative; Notice of Finding of No Significant Impact

AGENCY: Rural Utilities Service, USDA.

ACTION: Notice of finding of no significant impact.

SUMMARY: Notice is hereby given that the Rural Utilities Service (RUS), an agency delivering the United States Department of Agriculture (USDA) Rural Development Utilities Programs, has made a Finding of No Significant Impact (FONSI) with respect to a request from PowerSouth Electric Cooperative (PowerSouth) for assistance to finance the construction and operation of a new 360 megawatt peak-load natural gas-fired generation facility at PowerSouth's existing McIntosh Power Plant in Washington County, Alabama.

ADDRESSES: The FONSI is available for public review at USDA Rural Utilities Service, 1400 Independence Avenue, SW., Stop 1571, Washington, DC 20250–1571; and at PowerSouth's headquarters office located at 2027 East Three Notch Street, Andalusia, Alabama 36420. To obtain copies of the FONSI or for further information, contact Stephanie Strength, Environmental Protection Specialist, USDA, Rural Utilities Service, 1400 Independence Avenue, SW., Stop 1571, Washington, DC 20250–1571; Telephone: (202) 720–0468 or e-mail: *stephanie.strength@wdc.usda.gov;* or PowerSouth's headquarters office located at 2027 East Three Notch Street, Andalusia, Alabama 36420.

SUPPLEMENTARY INFORMATION: PowerSouth is proposing to construct a new 360 megawatt peak-load natural gas-fired generation facility at PowerSouth's existing McIntosh Power Plant with an in-service date of late 2010. The proposed project would consist of two 180 megawatt combustion turbine units operated by natural gas. Burns and McDonnell Engineering Company, Inc., an environmental consulting firm, has prepared an Environmental Analysis (EA) for RUS. Rural Utilities Service has conducted an independent evaluation of the EA and believes that it accurately assesses the impacts of the proposal and has determined that no significant impacts would result from the construction and operation of the proposal.

Any final action by RUS related to the proposed project will be subject to, and contingent upon, compliance with all relevant Federal environmental laws and regulations and completion of environmental review procedures as prescribed by the 7 CFR part 1794, Environmental Policies and Procedures.

Dated: May 29, 2009.

James R. Newby,

Acting Administrator, Electric Program, Rural Utilities Service.

[FR Doc. E9–13114 Filed 6–3–09; 8:45 am]

BILLING CODE 3410–15–P

DEPARTMENT OF AGRICULTURE

Forest Service

Lewis & Clark County Resource Advisory Committee Meeting

AGENCY: Forest Service, USDA.

ACTION: Notice of meeting.

SUMMARY: The Lewis & Clark County Resource Advisory Committee (RAC) will meet on Wednesday, June 10, 2009, from 6 p.m. until 8 p.m., in Helena, Montana. The purpose of the meeting is to conduct welcomes and introductions, review RAC charter, discuss the guidelines for Title II and Title III funding and proposals, discuss operating protocols, brief RAC members on available funding, capture and record preliminary project ideas, discuss outreach process for project proposals, set a next meeting date and receive public comment on the meeting subjects and proceedings.

DATES: Wednesday, June 10, 2009, from 6 p.m. until 8 p.m.

ADDRESSES: The meeting will be held at the USDA-Helena Ranger District office located at 2001 Poplar, Helena, Montana 59601 (MT 59601).

FOR FURTHER INFORMATION CONTACT: Kathy Bushnell, Committee Coordinator, Helena National Forest, 2880 Skyway Drive, Helena, Montana 59602, 406–495–3747; e-mail: *kbushnell@fs.fed.us.*

SUPPLEMENTARY INFORMATION: Agenda items to be covered include: (1) Welcome and Committee introductions; (2) Review and revise, if necessary, established RAC charter; (3) discussion of requirements related to Title II and

federal register

Tuesday
June 16, 1987

Part II

Department of Agriculture

Animal and Plant Health Inspection Service

7 CFR Parts 330 and 340

Plant Pests; Introduction of Genetically Engineered Organisms or Products; Final Rule

DEPARTMENT OF AGRICULTURE

Animal and Plant Health Inspection Service

7 CFR Parts 330 and 340

[Docket No. 87-021]

Introduction of Organisms and Products Altered or Produced Through Genetic Engineering Which Are Plant Pests or Which There is Reason To Believe Are Plant Pests

AGENCY: Animal and Plant Health Inspection Service, USDA.

ACTION: Final rule.

SUMMARY: This document establishes regulations for the introduction (importation, interstate movement, or release into the environment) of genetically engineered organisms and products which are plant pests or for which there is reason to believe are plant pests (regulated articles). The regulations set forth procedures for obtaining a permit for the release into the environment of a regulated article and for obtaining a limited permit for the importation or interstate movement of a regulated article. Such permits are required before a regulated article can be introduced in the United States. These regulations are necessary to prevent the entry into and dissemination and establishment of plant pests in the United States.

DATE: Effective date of final rule is July 16, 1987.

FOR FURTHER INFORMATION CONTACT: Terry L. Medley, Director, Biotechnology and Environmental Coordination Staff, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Room 408, Federal Building, 6505 Belcrest Road, Hyattsville, MD 20782, 301-436-7602.

SUPPLEMENTARY INFORMATION:

Background

On June 26, 1986, the Animal and Plant Health Inspection Service (APHIS) published a proposed rule entitled, "Introduction of Organisms and Products Altered or Produced Through Genetic Engineering Which Are Plant Pests or for Which There Is Reason to Believe Are Plant Pests" (51 FR 23352-23366 hereinafter referred to as the proposed regulations). The proposed regulations set forth procedures for obtaining a permit prior to the introduction (importation, interstate movement, or release into the environment) of genetically engineered organisms or products which are plant pests or for which there is reason to believe are plant pests (regulated articles).

The provisions that appeared in the proposed regulations and adpopted in this final rule concerning the ned to obtain a permit prior to introducing a regulated article are consistent with existing permit requirements in 7CFR Parts 300-399. Such requirements are imposed by APHIS in regulating the movement of non-genetically engineered organisms, products, and certain articles which are plant pests or could harbor plant pests. The final rule extends the regulation of certain organisms not genetically engineered to certain organisms that are genetically engineered.

Comments Received on Proposed Regulations

APHIS attempted to solicit as many comments as possible on its proposed regulations through public hearing held in Sacramento, California, on July 29, 1986, and in Washington, DC, on August 5, 1986, and through an extension of the comment period from August 25 to September 26, 1986 (51 FR 29401, August 15, 1986). Including the comments presented at the public hearings, APHIS received 184 comments on the proposed regulations. Commenters included academicians, businesses engaged in genetic engineering, trade associations, professional organizations, private individuals/consultants, State departments of agriculture, members of the U.S. House of Representatives, and a representative from a State legislature.

APHIS has carefully considered all the comments on the proposed rule.

Based on the rationale set forth in the proposed regulations and in this document, APHIS is promulgating a final rule which will become effective on July 16, 1987.

Under the final rule, a person has to obtain a permit to import, move interstate or release into the enviroment a genetically engineered organism or product only if:

(1) The organism has been altered or produced through genetic engineering from an organism (donor, vector, or recipient);

a. That is included in the list of genera and taxa in § 340.2 and such organism meets the definition of a plant pest; or

b. That is an unclassified organism and/or an organism whose classification is unknown; or

(2) The product contains such an organism (described in (1); or

(3) Any other organism or product (not included in (1) or (2) altered or produced through genetic engineering, which the Deputy Administrator determines is a plant pest or has reason to believe is a plant pest. Thus, this final rule regulates certain genetically engineered organisms and products that present plant pest risks, and, as explained in more detail below, does not regulate an article merely because of the process by which it was produced.

Many provisions, as noted below, have been changed in response to comments, which were generally constructive and often complex. Because numerous changes have been made to the regulations as originally proposed, a summary of those changes is presented at the outset of the preamble. The summary includes the number of the paragraph in which the rationale for the APHIS action is discussed. Following the summary is a detailed discussion of the relevant comments received, and APHIS' response to those comments. The preamble is organized to correspond with sections of the final rule.

SUMMARY OF CHANGES MADE IN THE FINAL RULE

Section	APHIS action	Paragraph No. of response
§ 340.1 Definitions:		
Certificate of exemption	Changed to courtesy permit	5
Classical genetics	Not adopted	6
Genetic engineering	Adopted new definition	7
Genetic manipulation	Not adopted	8
Mutagen	Not adopted	10
Organism	Amended by excluding prions and non-living components and parts	11, 21, 22
Pathogen	Not adopted	12
Plant	Amended by excluding bacteria, fungi, and prokaryotic algae	14
Regulated article	Adopted with revisions	16
§ 340.2 Groups of Organisms:		
Removed the following taxa		20, 21

SUMMARY OF CHANGES MADE IN THE FINAL RULE—Continued

Section	APHIS action	Paragraph No. of response
Prions.		
Rickettsial-like organisms associated with plant disease		
Added the following taxa or groups of organisms:		
Gram-negative xylem-limited bacteria associated with plant diseases		
Gram-negative phloem-limited bacteria associated with plant diseases		
Added petition procedure in § 340.4 to amend list of organisms.		42
§ 340.3 Permits:		
§ 340.3(a)	Added provisions for designation of confidential business information (CBI) material	24, 25
§ 340.3(b)	Added permit for environmental release with provisions for State notification and review; APHIS review to be completed in 120 days.	29, 31
§ 340.3(c)	Added limited permit for interstate movement or importation with provisions for State notification and review; APHIS review to be completed in 60 days.	30, 31, 32, 34
§ 340.3(d)	Added provisions for premises inspection prior to permit issuance	28
§ 340.3(f)	Did not adopt requirement to report death of a regulated article; substituted reporting of unanticipated characteristics or unusual occurrence (excessive mortality or morbidity or unanticipated effects).	39
§ 340.4 Certification of exemption	Did not adopt; substituted provision for courtesy permit in § 340.3(h); Section redesignated as "petition to amend the list of organisms."	34, 42
§ 340.5 Marking and identity	None	
§ 340.6 Container requirements:		
§ 340.6(c)	Added new section to allow variance from container requirements	43
§ 340.7 Costs and charges	None	

Comments on APHIS'Authority to Restrict the Introduction of a Regulated Article

1. Approximately thirty-one commenters prefaced their remarks with general statements supporting APHIS' approach in Part 340. The comments included backing for APHIS as "lead agency" and support of APHIS' authority pursuant to the Federal Plant Pest Act (FPPA) and Plant Quarantine Act (PQA) to regulate genetically engineered organisms as set forth in its proposed regulations. Seven commenters, however, alleged that APHIS lacks the authority under the provisions of the FPPA and PQA for the proposed rule. Specifically, the commenters indicated that the FPPA does not authorize APHIS to regulate "release into the environment," but only importation and interstate movement; and that the FPPA and Federal Noxious Weed Act (FNWA) and the Act of 1903 have no "beforehand testing" or pre-release review requirements to determine if new organisms might be pests, noxious weeds or contagious agents.

APHIS disagrees with the commenters who challenged APHIS' authority for the proposed rule. Is should be noted that APHIS never cited the Federal Noxious Weed Act (7 U.S.C. 2801 *et seq.*) or the Act of 1903 (21 U.S.C. 111 *et seq.*) as authority for promulgating a final rule under Part 340. Rather, APHIS cites as authority the Plant Quarantine Act (7 U.S.C. 151 *et seq.*) and the Federal Plant Pest Act (7 U.S.C. 150aa *et seq.*).

It is the Department's position that the provisions of the rule requiring a permit prior to the release into the environment of certain genetically engineered organisms or products containing such organisms is consistent with the legislative intent of the FPPA and is a reasonable construction of the Department's statutory responsibilities under the FPPA.

The FPPA was enacted to fill gaps in the Department's authority to protect American agriculture against invasion by foreign plant pests and diseases. It confers very broad authority on the Secretary of Agriculture to prevent the dissemination into the United States or interstate of plant pests.

The legislative history of the FPPA indicates that in addition to providing authority to regulate organisms that "can injure" plants or plants products, the FPPA provides authority to regulate organisms that might later be found to be injurious to cultivated crops. (See the Department's legal opinion concerning this issue, attached as Appendix G of "Issues in the Federal Regulation of Biotechnology: From Research to Release", a report prepared by the Subcommittee on Investigations and Oversight of the Committee on Science and Technology of the House of Representatives, 99th Cong., 2nd Session, December 1986).

2. One commenter who expressed the view that separate regulation of genetically engineered organisms is not authorized by the FPPA suggested that APHIS should amend its existing regulations rather than promulgate new regulations.

APHIS disagrees with this commenter and has determined that separate regulations for certain genetically engineered organisms are needed. Under the FPPA, APHIS can regulate plant pests whether they are naturally occurring or genetically engineered. APHIS' regulations in 7 CFR 330.200 are applicable to persons seeking to import, or move interstate plant pests which are naturally occurring and have not resulted from genetic engineering. APHIS believes that the regulations in 7 CFR 330.200 are not adequate to regulate the introduction (importation, interstate movement, or release into the environment) of genetically engineered organisms and products for two reasons. The regulations as presently written provide no way for the public to determine whether or not a genetically engineered organism or product would be deemed a "regulated article." Secondly, the data that is called for in a permit application under 7 CFR 330.200 would not provide APHIS with sufficient information to make a determination on the plant pest status of certain genetically engineered organisms or products. In short, APHIS determined that its existing regulations could not be readily amended to include the data elements that are needed to adequately regulate the introduction of genetically engineered organisms, and that separate regulations for genetically engineered organisms are required.

APHIS is not treating genetically engineered organisms and products which are plant pests or for which there is reason to believe are plant pests differently than so-called "established" plant pests or naturally occurring organisms which there is reason to believe are plant pests. In both cases, a permit must be obtained from APHIS prior to importation and interstate movement. In the case of certain genetically engineered organisms, APHIS has determined that the release

into the environment of certain genetically engineered organisms is tantamount to the introduction of a new organism. Further, living organisms do not acknowledge State lines. Therefore, a permit must be obtained from APHIS prior to release into the environment.

Comments on the Scope of the Proposed Regulations

3. Some commenters expressing support for APHIS' approach also expressed concern that the proposed rule was too broad and inclusive and needed modification to be practicable. Some commenters indicated that the proposed regulations would cause APHIS to be overwhelmed with applications for permits. Many commenters expressed the view that APHIS should have the ability to exclude certain products or classes of products from the regulations as experience indicates certain exemptions are justified.

APHIS agrees with commenters expressing the view that the proposed regulations were too broad and inclusive and has made several revisions to narrow the scope of the regulations.

As a means of eliminating the need for a "responsible person" to submit a new application for a limited permit for the interstate movement of a regulated article between contained facilities each time the person seeks to move the article interstate, APHIS has added provisions in § 340.3(c)(1) that would allow such movement to be made under the provisions of a single limited permit, which would be valid for one year. Such a permit could be renewed thereafter, if appropriate. This change should significantly eliminate the number of applications APHIS will have to process, and significantly reduce the number of applications that would have to be submitted. (See paragraph 32.) Further, as discussed in more detail in paragraphs 11, 16, and 19, APHIS has amended the definitions of "organism", and "regulated article", as well as the list of organisms in § 340.2. These changes narrow the scope of the final rule.

In addition, in order to facilitate the addition or removal of certain genera, species, or subspecies of organisms on the list in § 340.2, APHIS has included provisions in §340.4 of the final rule for a person to submit a petition to amend the list of organisms. (See paragraph 42.)

Comments Requesting that APHIS Not Regulate Research

4. Sixty-eight comments were received from academic researchers and/or institutions expressing opposition to APHIS' regulation of the introduction (importation, interstate movement, or release into the environment) of regulated articles. The majority of the commenters argued that this amounts to the regulation of research and that biotechnology research can be regulated by the research community itself using institutional biosafety committees and the USDA Guidelines that were set forth in the Advanced Notice of Proposed USDA Guidelines for Biotechnology Research. (See 51 FR 23387–23393) These commenters argued that a clear distinction exists between research and product development, and that APHIS should regulate only when a product is involved.

APHIS disagrees with those commenters that believe that the agency is regulating research. APHIS believes that the regulation of the introduction of certain genetically engineered organisms does not amount to regulation of research, but rather regulation of movement and release into the environment of a regulated article. The final rule does not attempt to prescribe what a person can or cannot do in a laboratory or contained greenhouse, but rather, under what conditions a regulated article can be moved or released. It should be noted that a person does not become subject to these regulations until the person seeks to *introduce* genetically engineered organisms. Thus, APHIS does not believe that the final rule is an attempt to regulate research.

APHIS also disagrees with the comments that argued that APHIS should only become involved when a "product" is involved; there is no statutory limitation in the FPPA or PQA for APHIS to regulate in such a manner. APHIS' statutory responsibility is to take those measures necessary to prevent the introduction into the United States of "plant pests."

Comments on Definitions (§ 340.1)

The definitions of key words in proposed Part 340 collectively generated the largest number of comments on a single section. Comments on the individual definitions and APHIS' response are presented in alphabetical order.

Certificate of Exemption

5. No change has been made in this definition, but the name has been changed to "courtesy permit." For a discussion of the comments and explanation of the rationale for the change see paragraph 34.

Classical Genetics

6. The six comments on this definition generally indicated that it should have included such processes as protoplast, cell, and embryo fusion, and mutagenesis, because such processes have traditionally been associated with classical genetics techniques. APHIS agrees with this assessment, and has revised the definition of "genetic engineering" to exclude reference to classical genetics as well as protoplast, cell, and embryo fusion, and mutagenesis. An examination of the literature describing the techniques used in genetics prior to the introduction of recombinant DNA technology finds that many techniques other than interspecific crosses have been in common use. The transfer of genetic traits by methods such as protoplast, cell, and embryo fusion, and mutagenesis has been an accepted part of genetics for some years prior to the development of various recombinant DNA technologies for the movement of genes. It would thus seem that the techniques in question should properly be included as a part of classical genetics, and excluded from the definition of "genetic engineering."

As a result of the change in the definition of "genetic engineering" to exclude reference to classical genetics, the definition of "classical genetics" has been deleted.

Genetic Engineering

7. The twenty-three comments on this definition generally expressed the view that such techniques as protoplast, cell, and embryo fusion, and mutagenesis encompass classical genetic processes.

For the reasons stated in paragraph 6 above on classical genetics, APHIS agrees with the comments that specific techniques such as protoplast, cell and embryo fusion, and mutagenesis should not be included in "genetic engineering." A new definition has been provided, as follows: "The genetic modification of organisms by recombinant DNA techniques." It should be noted that if a new organism or product was produced using classical genetic techniques, and the new organism was a plant pest, it would be regulated pursuant to a similar permit system found in 7 CFR 330.200.

Genetic Manipulation

8. Because the definition of genetic engineering has been modified and the term genetic manipulation is not used in the current definition of that term, APHIS has deleted the definition of genetic manipulation.

Introduce

9. Two comments were received on the definition of introduce. One commenter suggested that the definition be expanded to include "creation of a new organism or genotype" in addition to importation, interstate movement, and release into the environment. The commenter argued that the regulation of genetic engineering should begin with the development of the organism in the laboratory.

As previously stated, the final rule does not regulate laboratory research conducted at contained facilities. The responsibility at USDA for the oversight of biotechnology research is delegated to the Assistant Secretary for Science and Education. APHIS believes that if the laboratory is a contained facility, such regulation by APHIS would be unnecessary from the standpoint of preventing the introduction of genetically engineered organisms which are plant pests or which there is reason to believe are plant pests, and would, therefore, be beyond APHIS' statutory authority.

Another commenter expressed the view that the term introduce or introduction is somewhat redundant in that it overlaps with the definition of release into the environment, and that the term "release into the environment" should be dropped from the definition of introduce.

APHIS disagrees with the commenter that inclusion of the phrase "release into the environment" is redundant. Inclusion of the phrase "release into the environment" in the definition of introduce is meant to advise persons that APHIS is regulating the release into the environment of a regulated article, in addition to regulating interstate movement and importation. According to § 340.0(a) of the final rule, no person shall *introduce* (release into the environment) a regulated article unless the introduction is authorized by a permit and the introduction is in conformance with all of the applicable restrictions in this part.

Mutagen

10. Because the definition of genetic engineering has been modified and the term mutagen (mutagenesis) is not used in the current definition, APHIS is deleting the definition of mutagen.

Organism

11. The twelve comments on the definition as proposed expressed the view that it was too broad and should not include portions of organisms. APHIS agrees with these comments, and has deleted the language "and any part, copy, or analog thereof, including DNA, RNA, which is infectious."

The original definition of organism included these constituent parts, which are not included in any currently accepted concept of the nature of an organism. APHIS has reviewed this question, and determined that the separate constituent parts of an organism can not be regarded as "living", and do not present the same plant pest risk that the complete or intact organism may pose. This is not to deny that some components, such as DNA sequences, or organisms, which are plant pests may not present some risk if they are incorporated into other organisms. However, it has been determined that it is possible to regulate the risk associated with these cell components without restoring to the inclusion of these non-living constituents as organisms. This is because a genetically engineered organism which contains these components from an organism listed in § 340.2 would be deemed a regulated article.

Prions have also been deleted from this definition, and from the list of organisms in § 340.2. The reasons for the deletion are explained in the discussion of the comments on § 340.2.

An amended definition has been adopted, as follows: "Any active, infective, or dormant stage of life form of an entity characterized as living, including vertebrate and invertebrate are animals, plants, bacteria, fungi, mycoplasmas, mycoplasma-like organisms, as well as entities such as viroids and viruses, or any entity characterized as living, related to the foregoing."

Pathogen

12. Because the definition of regulated article has been modified and the term pathogen (pathogenic) is not used in the current definition, APHIS is deleting the definition of pathogen.

Person, Responsible Person

13. One commenter noted that the proposed regulations contained definitions of the terms "person" and "responsible person." The commenter asked, "who is responsible, the individual or the individual and his corporation?

The final rule aplies to either a single person when acting alone when there is no corporation or other legal entity, or the person designated by the corporation or other legal entity to be the responsible person and the corporation or other legal entity, when the responsible person is acting within the scope of his or her employment of the corporation.

Plant

14. The majority of the seventeen commenters on this definition pointed out that it was not consistent with the classification of organisms in § 340.2 of the proposed regulations. These comments noted that the definition of plant included bacteria, but that bacteria was not listed under the Kingdom Plantae; bacteria had been listed under the Kingdom Monera. The commenters argued that bacteria should not be included in the definition of plant

Other commenters objected to the inclusion of fungi and prokaryotic algae in the plant kingdom. One commenter noted that the inclusion of such organisms in the plant kingdom fails to consider the results of twenty-five years and more of comparative biochemistry concerned with the structure and function of cells.

APHIS agrees with these comments, and has accordingly deleted bacteria, fungi, and prokaryotic algae from the definition.

An amended definition has been adopted, as follows: Any living stage or form of any member of the plant kingdom including, but not limited to eukaryotic algae, mosses, club mosses, ferns, horsetails, liverworts, angiosperms, gymnosperms, and lichens (which contain algae) including any parts (e.g., pollen, seeds, cells, tubers, stems) thereof, and any cellular components (e.g., plasmids, ribosomes, etc.) thereof.

Plant Pest

15. Nine comments were received on the definition of plant pest. The commenters indicated that the definition was very broad and overly inclusive, that it included numerous examples of nonpathogenic organisms, and that it failed to adequately notify applicants of the characteristics or criteria to enable a determination of non-pest status.

APHIS acknowledges that the definition of plant pest is very broad. However, APHIS disagrees that the definition is overly inclusive, and the definition has been adopted as proposed. The definition of plant pest comes from the definition of plant pest found in the FPPA (7 U.S.C. 150aa *et seq.*). As discussed in response to paragraph 1, the definition of plant pest was deliberately made broad by Congress to include those organisms that might *later* be found to be injurious to plants. APHIS has determined that all of the types of organisms included in the definition of plant pest have been

known to directly or indirectly injure or cause either disease or damage in plants, or in plant parts, or in processed, manufactured, or other products of plants. APHIS believes that the definition of plant pest indicates to a person that an organism that does not have plant pest status would be one that does not directly or indirectly injure or cause disease or damage in any plants, or plant parts, or any processed, manufactured, or other products of plants.

Regulated Article

16. Thirty-four comments were received on the definition of regulated article. Fifteen of these comments expressed the opinion that the proposed definition of regulated article was too broad. Some commenters stated that as defined "regulated article" could be interpreted in a way that would include many organisms that the commenters did not consider to be plant pests. In many cases commenters identified specific organisms that they stated were not plant pests, and thus should not be subject to regulation. Other commenters stated that the inclusion of non-living components of plant pest organisms should not be included as a regulated article.

APHIS agrees with these comments, and has modified the final rule in several respects to narrow the scope of regulated article.

First, the list of organisms in § 304.2, which would cause a genetically engineered organism or product to be deemed a "regulated article," has been modified, by deleting certain organisms and by clearly stating how the list is to be utilized. Secondly, the definition of organism has been modified to exclude non-living components or parts of organisms listed in § 340.2. Lastly, APHIS has modified the definition of regulated article to indicate that an organism which belongs to any genera or taxa designated in § 340.2 must meet the definition of "plant pest" or be an unclassified organism and/or an organism whose classification is unknown, or contain such an organism, or any other organism which the Deputy Administrator determines is a plant pest or has reason to believe is a plant pest. The change is significant since it would affect whether the genetically modified organism is deemed a regulated article.

The following new definition has been adopted: "Any organism which has been altered or produced through genetic engineering if the donor organism(s), recipient organism(s), or vector or vector agent(s) belongs to a genera or taxa designated in § 340.2 of this part and meets the definition of plant pest, or is an unclassified organism and/or an organism whose classification is unknown, or any product which contains such an organism, or any other organism or product altered or produced through genetic engineering which the Deputy Administrator determines is a plant pest or has reason to believe is a plant pest. Excluded are recipient microorganisms which are not plant pests and which have resulted from the addition of genetic material from a donor organism where the material is well characterized and contains only non-coding regulatory regions." (The rationale for the exclusion for certain microorganisms is discussed in paragraph 18).

Several commenters suggested that APHIS add procedures which would provide for the exclusion of organisms altered by recombinant methods, which are not plant pests.

APHIS agrees with the commenters and believes that the petition procedure discussed in paragraph 42 is responsive to the commenters' concerns.

Several commenters suggested that the delegation of authority to the Deputy Administrator to designate an organism as a "regulated article" based upon "reason to believe" was a standardless delegation of authority.

APHIS disagrees with these comments. The provision for the Deputy Administrator to designate an organism as a regulated article based upon "reason to believe" has been retained.

Section 105 of the FPPA grants the emergency authority to regulate an organism, where there is reason to believe it is a plant pest or in order to prevent the dissemination into the United States of a plant pest. With regard to conventional plant pests, the Deputy Administrator of APHIS has used this authority when it was necessary to regulate an organism that was likely to be a plant pest and was not otherwise specified because of plant pest risk as a regulated article. "Reason to believe" is based on scientific information, such as taxonomic association and biological data. This standard is an objective, not subjective one.

An example of the use of "reason to believe" occurred in 1982 when a previously undescribed disease was observed on lime trees in Southwestern Mexico. APHIS regulations prohibit entry of citrus fruit from countries where citrus canker is present. Initially it proved difficult to make a specific identification of the pathogen associated with this disease. Because the pathogen belonged to the bacterial genus *Xanthomonas*, and because the disease caused lesions on citrus leaves, it was determined that there was reason to believe that the disease in Mexico was citrus canker, and that the organism associated with the disease was a plant pest. This resulted in various actions being taken to prevent the introduction of the disease into the United States. Subsequent research conducted in the United States and Mexico confirmed that the organism causing the disease in Mexico was *Xanthomonas campestris* pv. *citri*, a regulated plant pest.

The decision by APHIS to designate an organism as a regulated article based upon the "reason to believe" provision will be an objective, informed decision made after review of substantive information regarding demonstrated plant pest risks. It will not be an arbitrary one.

Release into the Environment

17. Of the eighteen comments on this definition, the largest number concerned the fact that the proposed definition relied only on physical containment, and ignored biological containment. Other commenters requested a definition of contained greenhouse, expressed approval of the definition, or suggested various approaches to the evaluation of containment.

One commenter indicated that a general understanding of this term has been that release occurs if an experiment does not take place within the confines of a laboratory where the organism can be physically contained and remedial measures taken in the event of an accident. APHIS agrees with the commenter and believes that the concept of release should be based on the concept of a release from the confines of physical containment. One commenter suggested regulating release only if there is a deleterious alteration of the environment. APHIS believes that what is "deleterious" to the environment is too subjective a standard. USDA believes that a release from physical confinement is more understandable and a practical standard.

APHIS has adopted the definition of "release into the environment" as originally proposed. APHIS believes biological and greenhouse containment are key issues in discussions concerning this definition. While the definition of release into the environment does not formally include the concept of biological containment (i.e. the inability of the regulated article to survive outside specific environmental or host conditions) APHIS believes that biological containment is one important factor in determining the prescribed level of physical containment. Since greater scrutiny is needed to judge the

efficacy of biological containment than physical containment. APHIS does not believe a claim of biological containment is sufficient to exempt a party from the requirement of having to obtain a permit for the release of a regulated article into the environment. In APHIS' review of permit applications, determinations of the adequacy of biological containment will vary according to the subject organism and quality of scientific evidence, and will be made on a case-by-case basis. In its review process, APHIS will allow biological containment in lieu of physical containment if it determines this will prevent the dissemination and establishment of plant pests in the United States.

APHIS does not believe it is practical to try to define what is a "contained greenhouse", since what is considered adequate physical containment will vary according to the subject organism, and that such determination must be made on a case-by-case basis. For example, physical containment will depend upon combinations of laboratory practices, containment equipment, and special laboratory design. APHIS will review the data submitted in a permit application concerning the description of a "contained facility" in determining whether the contained facility is adequate to prevent the release into the environment of the genetically engineered organism. A person should consult the NIH Guidelines at 51 FR 16958, "Appendix G—Physical Containment", for guidance on what are appropriate methods of physical containment.

APHIS acknowledges that the Biotechnology Science Coordinating Committee, the National Institutes of Health, and the Environmental Protection Agency are all attempting to define what constitutes release into the environment. If a uniform definition is adopted by these groups APHIS shall consider proposing to amend the final rule to incorporate such a definition.

Well-Characterized and Contains Only Non-Coding Regulatory Regions; Exclusion for Certain Microorganisms

18. A total of nineteen comments were received on this exclusion from the definition of regulated article. It was proposed to exclude microorganisms that are "non-pathogenic, non-infectious, and otherwise not plant pests that have resulted from the addition of genetic material that is well characterized and contains only non-coding regulatory regions."

The comments on this provision ranged from doubt about the scientific soundness of such an exclusion to requests that the exclusion be retained and expanded to include other non-coding regions.

Based upon a review of these comments and the scientific literature, it was determined that there is no evidence that the addition of well-characterized non-coding regulatory genes from a prokaryote or eukaryote to a prokaryote has resulted in the *de novo* appearance of a gene product which did not exist prior to the acquisition of the new genetic material. The scientific literature indicates that regulatory, transcriptional or translational ambiguities are not found in the transfer of well characterized genetic material between prokaryotes, or from eurkaryote to prokaryote, but do occur in prokaryote to eukaryote transfers.

One commenter indicated that some pathogens have the capacity to increase in virulence or change in host range in response to a single gene mutation and that some avirulent derivatives of pathogens have the potential to regain pathogenicity by mutation. The commenter stated that such microorganisms need to be examined before release to the environment. However, the commenter noted that a distinction must be made between a derivative of a pathogen, potentially harmful, and a nonpathogenic organism bearing an introduced gene from a pathogen.

APHIS agrees with the commenter that if the recipient microorganism is not a pathogen or a plant pest the microorganism after the addition of genetic material which is well characterized and contains only non-coding regulatory regions, will also not be a pathogen or a plant pest. Therefore, as adopted in the final rule, recipient microorganisms which are not plant pests and which have resulted from the addition of genetic material from a donor organism which is "well characterized and contains only non-coding regulatory regions" are not regulated articles. However, if the recipient microorganism was a plant pest, the addition of such genetic material would not lessen the fact that the recipient microorganisms presents a plant pest risk, and as such, would be a regulated article.

One commenter suggested that other non-coding regions such as ribosomal RNAs, tRNAs, and RNAs as required for replication also be exempted from review because these do not encode proteins.

APHIS disagrees with the commenter. The reason that the exclusion cannot be currently extended to other specific non-coding, non-regulatory regions such as ribosomal RNAs, tRNAs, and RNAs required for replication is that most of these aforementioned genes are part of a complex interdependent system of operons. These operons generally contain a very wide array of disconnected functions which interact with other related and unrelated operons to poroduce critical non-structural proteins which are needed in equimolar amounts. Therefore, the consequences of the genetic transfer of this level of genetic complexity, even between bacteria, are not well understood, and could have unforeseen results. APHIS believes there may be significant potential plant pest problems present in this type of gene transfer if the exclusion were more extensive.

Commenters argued that "knowing the exact nucleotide base sequence of a regulatory element or the transfer of non-coding regulatory sequences" does not allow one to predict the biological role of this element when placed in another organism.

APHIS disagrees with the commenters. In the case of [the transfer between prokaryotes or eukaryotes to prokaryotes] "well-characterized non-coding regulatory genes," there is absolute predictability of the biological role of these genetic elements, and it can only execute its original predetermined regulatory function.

One commenter argued that it did not make sense to exempt only non-coding sequences. The commenter indicated that almost all "coding" sequences should be given exempt status such as cloned sequences. Another commenter noted that there are many well-characterized *coding* regions, which have no known or expected hazard to health or the environment, which should also be excluded.

APHIS disagrees with the commenters who believe that microorganisms which have resulted from the addition of genetic material which contains coding regions should also be exempt.

With the exclusion for microorganisms as modified in the final rule, it is impossible for the benign recipient to acquire new structural genes or gene products. The exclusion of well-characterized *coding* genes could result in the acquisition of deleterious new or novel gene products in a benign recipient. Therefore, the commenter's suggestion has not been accepted.

One commenter suggested modifying the definition of well-characterized and contains only non-coding regulatory regions. The commenter suggested modifying the definition by eliminating section (c) of the definition because it is redundant to sections (a) and (b) and by revising section (c) to indicate that the

transferred genetic material must be non-coding in the new host microorganism.

The modification of the definition as suggested by the commenter is unnecessary. There is no evidence to support the commenter's suggestions that a non-coding gene from a donor microorganism could be a coding gene in a recipient microorganism.

One commenter noted that the precision in molecular biological experiments must not be confused with precision in predicting their ecological consequences. The commenter indicated that this alteration of the organism as a whole or its relationship to other organisms in the environment would be unknown, and that such regulatory changes in the organism can create "novel" organisms which are eminently suited to disrupt ecological niches.

APHIS disagrees with the commenter's assertion that a novel or new organism would be created as a result of the addition of genetic material that contains only well-characterized non-coding regulatory regions. APHIS believes that in this specific case, the absolute understanding of the underlying molecular genetic mechanism is the sole determinant in being able to predict the plant pest characteristics of the modified microorganism. It is APHIS' position that when donor genetic material from an organism which is well characterized and contains only non-coding regulatory regions is placed into a benign receipient microorganism, the recipient will not acquire plant pest traits or become a plant pest.

Furthermore, APHIS believes that the genetic manipulations which create such a microorganism would be similar to the same type of genetic manipulations which occur in nature through mutation and natural selection (the higher or lower production of a pre-existing structural gene) or through classical breeding techniques which man has been using for the past 10,000 years. In short, such a modified microorganism would be so close to ones produced by natural mutational events or selective breeding programs (classical techniques) that there is no reason to believe that such a microorganism would be a plant pest. Furthermore, APHIS believes that the possibility of harmful ecological consequences would not be considered significant.

Comments Concerning the List of Organisms in (§ 340.2)

19. Fifty-two comments were received on the list of organisms in § 340.2, which are or may contain known plant pests or for which the Department has reason to believe are plant pests. The commenters generally expressed the view that the list was overly broad and inclusive, and that only organisms known to be plant pests should be included. Other comments were received which objected to the inclusion of various taxa or groups of organisms which commenters argued were not plant pests.

APHIS agrees with those commenters that believe that the list was overly broad and inclusive, and agrees that only organisms from any genera or taxa listed in § 340.2 and that meet the definition of "plant pest" should be regulated. APHIS has made several revisions in the final rule to implement this change.

APHIS has revised the prefatory language in § 340.2 of the rule, which explains how to determine if an organism classified in an unlisted taxa which comes under a higher listed taxa would be deemed to be a plant pest. Further, APHIS has amended the definition of "regulated article" to indicate that an organism which belongs to any genera or taxa designated in § 340.2 must meet the definition of plant pest before it is deemed a regulated article. In addition, APHIS has added the following new footnote 4 to § 340.2 which explains the conditions that must be met before an organism is deemed a plant pest.

An organism belonging to any taxa contained within any listed genera or taxa is only considered a plant pest if the organism "can directly or indirectly injure, cause disease, or damage in any plants or parts thereof, or any processed, manufactured, or other products of plants." Thus, a particular unlisted species within a listed genus would be deemed a plant pest for purposes of § 340.2 if the scientific literature refers to the organism as a cause of direct or indirect injury, disease, or damage to any plants, plant parts, or products of plants. [If there is any question concerning the plant pest status of an organism belonging to any listed genera or taxa, the person proposing to introduce the organism in question should consult with APHIS to determine if the organism is subject to regulation.]

As the language in the footnote indicates, an organism is not necessarily considered to be a plant pest, and thus subject to regulation, simply because the organism is a member of any listed genera or taxa. The list of genera or taxa in § 340.2 is presented as a list of all taxa which may contain plant pests. Within any listed genus or taxon, the organisms subject to regulation as plant pests are only those organisms that meet the statutory definition of plant pest (i.e., causes injury, disease, or damage in plants, plant parts, or products of plants). In most cases, organisms that are known to be plant pests will be referred to or discussed in the scientific literature. APHIS' reveiew of the scientific literature involves a search of the relevant agricultural data bases which include, but are not limited to Agricola, Biosis Previews, Cab Astracts, Agris International, Life Sciences Collection, and Supertech.

In addition to all those species for which the plant pest status can be determined by reference to the scientific literature, there will be certain other species or organisms for which the plant pest status will be unclear, due to such things as problems with taxonomic designation. If there is any question concerning the plant pest status of any species or organism belonging to any listed genera or taxa, the person proposing to introduce the organism in question should consult with APHIS to determine if the organism is subject to regulation.

This procedure for determining if an organism is subject to regulation under Part 340 is the same type of determination that must be made when a person proposes to import or move interstate non-genetically engineered organisms that may be subject to regulations promulgated under the FPPA and PQA and found in 7 CFR 330.200.

Lastly, for the reasons discussed in the proposed regulations of June 26, 1986, published in the **Federal Register** at 51 FR 23355, unclassified organisms and/or organisms whose classification is unknown are also included in § 340.2.

20. Many comments contained statements that various groups of organisms listed in § 340.2 should be removed from the list because these organisms are not plant pests. The groups of organisms most frequently mentioned in these comments were the bacterial genera *Rhizobium* and *Bradyrhizobium*, and various groups of mycorrhizal fungi.

However, those commenters did not present sufficient data to justify excluding *Rhizobium*, *Bradyrhizobium*, and various groups of mycorrhizal fungi from the list of organisms in § 340.2.

These taxa or groups of organisms contain organisms that are able to infect plants and survive at the expense of the host plant. The interaction between the infecting organism and the host plant is usually regarded as a symbiotic one, with the plant benefiting from the increased availability of essential nutrients. However, because the groups of organisms in question contain species that are well adapted to infecting and surviving in their plant hosts, it was determined necessary to retain these groups on the list in § 340.2. It should be noted that new § 340.4 provides the

procedures for amending the list of organisms in § 340.2.

The list in § 340.2 is composed of all those genera or taxa which may contain organisms that are plant pests. Within any taxonomic series, the lowest unit of classification actually listed is the group which is composed of, or includes, organisms that are regulated. Organisms belonging to all lower taxa contained within the group that is listed are included as organisms which are or may contain plant pests, if they otherwise meet the definition of plant pest as explained above. For example, when the lowest unit listed of a particular series is an order, then members of all families, genera, and species belonging to that order are meant to be included as organisms which are or may contain plant pests, if such organisms meet the statutory criteria for being a plant pest.

In a second example, if an order is included on the list, but is followed by a listing of one or more of the families belonging to that order, then only the members (all genera and species) of those families listed that meet the definition of plant pest are intended to be regulated. Members of any other families within that order that are not listed are not regulated.

It is crucial to note that an organism of any genera or taxa listed in § 340.2 is significant only when the organism meets the definition of a plant pest and two additional conditions are met. The organism must have been modified in some way through the process of genetic engineering (as defined in § 340.1), and there must be the intention to import the organism, to move the organism interstate, or to release the organism in the environment. If an organism is listed in § 340.2 but does not meet both the condition of movement or release to the environment, and of being modified by a process of genetic engineering, it is not regulated under Part 340.

Finally, it should be noted that all other regulations which affect the importation or movement of an organism which is a plant pest or could harbor a plant pest remain in effect regardless of the status of the organism under Part 340. To remind persons of this fact the following language has been added to footnote 1.

Under regulations promulgated in 7 CFR "Subpart-Nursery Stock" a permit is required for the importation of certain classes of nursery stock whether genetically engineered or not. Thus, a person should consult those regulations prior to the importation of any nursery stock.

21. Several comments were received which contained statements that the list of organisms in § 340.2 includes groups which have an incorrect taxonomic designation or that the list is incomplete with regard to the Kingdom Monera. In response to these comments, APHIS scientists reviewed the list of organisms and determined that certain changes were appropriate.

Taxonomy is a dynamic branch of the biological sciences, and is particularly so when the organisms being classified are in taxa or genera that have only recently been identified. After consulting the current literature, the following changes are made in the list of organisms in § 340.2.

Prions have been removed from the list of organisms which are or contain plant pests in § 340.2. There is no evidence at the present time that any prion is associated with a plant pest. All of the prions identified to date have been associated with diseases in animals. If in the future a prion should be found to be associated with a plant pest or suspected of causing a plant disease that organism could be added to the list.

The group of organisms previously referred to as Rickettsial-like organisms associated with plant disease are correctly described as gram-negative xylem-limited bacteria associated with plant diseases. Examples of diseases associated with these pathogens are Pierce's disease of grape and phony disease of peach.

Some organisms previously thought to be mycoplasma-like organisms (MLO) are in fact true bacteria and should be correctly listed as gram-negative phloem-limited bacteria associated with plant diseases. Examples of organisms in this group are the bacteria which are associated with citrus greening disease and clover club leaf disease.

Concerning those comments that the list is incomplete, APHIS is conducting a further examination of the plant pest status of members of various taxa in the Kingdom Monera to determine if additional taxa should be added to the list or if a more specific and exact listing can be proposed for members of some of the genera listed. If APHIS' research indicates additional taxa should be included in § 340.2 or if the list should be made more specific, a document shall be published in the Federal Register proposing to add such taxa or otherwise to revise the list.

Items Exempt From Regulation and Procedures for Removing Organisms From the List

22. Thirty-nine comments contained statements objecting to the inclusion of various organisms or portions or constituents of organisms as plant pests. Many comments contained statements that various portions (plasmids, DNA fragments, etc.) of plant pests be exempted from regulation if these components are "non-pathogenic." Some comments contained the suggestion that "disabled" pathogens not be regulated as plant pests.

In response to these comments, APHIS has modified the definition of organism so that this definition as amended now excludes parts or components of organisms listed in § 340.2. As previously stated, the definition proposed by APHIS for organism has been revised, and now excludes non-living components of living organisms. The reasons for this change have been previously explained in paragraph 11. Any organism containing these parts or components would be regulated if the parts or components were incorporated into the organism through the process of genetic engineering (as defined in § 340.1).

The movement of killed organisms that are included in the list of organisms in § 340.2 is not regulated. The movement of non-living components (including, but not limited to, DNA, RNA, and plasmids) of organisms included on the list of organisms in 340.2 is not regulated. However, if certain components of regulated plant pest organisms, including DNA and RNA sequences, organelles, and plasmids retain their identity and are incorporated as part of an organism, then the introduction of this organism would be regulated under Part 340. It was not APHIS' intent to imply that all species, biotypes, lines, or races of the taxa listed in proposed § 340.2 were plant pests. For example, *Erwinia caritovora* is a bacterial plant pathogen causing soft rot diseases. All members of the genus *Erwinia* are included in the list of organisms in § 340.2. If this organism is modified by the process of genetic engineering, the modified bacteria are subject to regulation under Part 340. If genetically engineered bacteria of this species are killed, then the killed cells and/or any parts or components (including DNA and RNA sequences) that might be extracted from them are not subject to regulation. Should any genetic material from these killed bacteria, including DNA and RNA or other component as noted at the beginning of § 340.2, be introduced into any living organism by the process of genetic engineering, then that organism would be subject to regulation under Part 340.

23. Many comments expressed concern about the inclusion of certain organisms as plant pests. In many cases these organisms are members of a group containing many plant pests, such as the

bacterial genera *Pseudomonas, Xanthomonas,* and *Erwinia.* Commenters frequently requested that specific organisms belonging to these groups which were believed not to be plant pests be removed from the list. These requests were based on conclusions and opinions, rather than any complete submission of factual material.

Organisms or groups of organisms are considered to be on the list of organisms in § 340.2 if they meet the statutory definition of plant pest. To determine if a particular species is a plant pest, a person should consult the scientific literature or APHIS to determine if the species has plant pest characteristics, as discussed in footnote 4 above.

APHIS recognizes that there may be instances when it may be appropriate to remove specific organisms from the list because they do not appear to be plant pests. Provisions for submitting a petition to remove a specific organism or group of organisms from the list are discussed in § 340.4. Any person may submit a petition to remove an organism or group of organisms from the list in § 340.2. The petition should include full and factual information supporting the request for removal.

Comments on Permits for the Introduction of a Regulated Article (§ 340.3)

Numerous comments were received on § 340.3 of the regulations pertaining to the issuance of a permit for the introduction of a regulated article. The comments pertained to: The need for additional provisions to protect confidential business information; the 180 day review period for processing permit applications; data required in applications; the need for state involvement in the review process; certificate of exemption/courtesy permits; the need for additional safeguards to be added to the final rule; and the standard permit conditions.

Confidential Business Information

24. One commenter suggested that it would be beneficial if the regulations contained specific instructions to an applicant in order to identify and protect confidential business information (CBI).

APHIS agrees with the commenter, and has revised § 340.3(a) of the final rule to include provisions advising applicants how CBI should be designated and submitted. Under § 340.3(a) the responsible person should submit two copies of a permit application. If there is CBI information contained in the application, then each page of the application containing such information should be marked "CBI Copy." In addition, those portions of the application deemed CBI should be so designated. The second copy of the application should have all such CBI deleted and should be marked on each page of the application where CBI was deleted "CBI Deleted." If an application does not contain CBI, then the first page of both copies of the application should be marked "No CBI."

APHIS believes that such procedures will readily identify those applications which contain CBI and will specifically designate those portions which the applicant feels must be protected. In addition, by requiring that an applicant submit a second copy of an application with CBI deleted, this will provide APHIS with a copy of the application which can be routinely sent to the State departments of agriculture for their notification, and review of the application and to requesting public interest groups without concern that CBI data might not be properly safeguarded.

25. Other comments acknowledged that the APHIS policy statement on CBI (See 50 FR 38561–38563, September 23, 1985) was an important element in USDA's regulatory program, but that it is important that these same procedures apply equally to any individual outside of APHIS, at other USDA agencies, that handle CBI in connection with an APHIS action.

APHIS agrees with these commenters. It should be noted that if CBI is made available to other government employees at other USDA agencies, such employees are prohibited under the Trade Secrets Act (18 U.S.C. 1905 *et seq.*) from disclosing such information. The Trade Secrets Act imposes serious criminal penalties for violating its provisions, and those government employees handling CBI are aware of the need to safeguard CBI. In addition, the USDA is drafting CBI materials specifically for the Office of Agricultural Biotechnology (OAB) which is the office which coordinates biotechnology research for the Science and Education Administration. These CBI materials will include a "Guide for the Control of Confidential Business Information Relating to Proposals for Approval of Biotechnology Research," and a "Commitment to Protect Confidential Business Information Form," to be signed by any person who receives CBI in an official capacity through the OAB.

180 Day Review Period for Processing Permit Applications

26. Fifty-three comments were received on the proposed provisions of the regulations which provided for a 180 day period for the review of permit applications.

The comments ranged from the observation that 180 days was "too long" to more strongly worded statements that such a delay was "unreasonable, unacceptable, and untenable." Approximately half the commenters (25) on the 180 day review period suggested a shorter review period and/or structured review procedures.

One commenter suggested that the review period should be no longer than 60 days. Other commenters expressed the view that applications should be reviewed for their completeness within 45 days, with a final decision being made in 90 days. The commenters suggested that for complicated applications, there could be a provision for an extended review of up to 120 days if the applicant and APHIS so agreed.

Most commenters suggested that a 90 day review period would be reasonable and in accord with the processing time for a pre-manufacturing notification (PMN) submitted to EPA under the Toxic Substances Control Act.

Nearly a quarter of the comments on this issue objected to the fact that in the proposed review period, APHIS did not distinguish between the different types of permits people would be requesting. These comments expressed the view that release into the environment and interstate movement or importation were separate activities and should be treated as such. One commenter suggested that 14 days would be a more appropriate period for the issuance of a movement permit.

APHIS agrees with the commenters that believe the proposed 180-day review period should be reduced and that the review period should vary according to the type of permit being issued.

APHIS has adopted a 120-day period, rather than a 60-day or 90-day time period time to review an application for release into the environment for two reasons. First, before APHIS issues a permit for release, a thorough and comprehensive environmental assessment must be prepared. Because of the doctrine of "Functional Equivalency," the EPA, which by statute must review a PMN within 90 days from receipt of a complete PMN, does not have to prepare an environmental assessment during the review period. APHIS has determined it necessary to prepare environmental assessments pursuant to the National Environmental Policy Act (NEPA) prior to issuance of a permit for release into the environment. Therefore, APHIS believes that it needs 120 days to review a permit application for environmental release. In the event an environmental impact statement

(EIS) has to be prepared, the review period would be extended. Secondly, the final rule, as revised, provides that before APHIS issues a permit for environmental release it shall submit a copy of the application for State notification and review. Because of the necessity to coordinate and consult with the State where release shall occur, APHIS believes it's advisable to allow for more than a 60-day review period.

It should be noted that 120 days would be the *maximum* time APHIS would need to review a complete application for environmental release that does not involve the preparation of an EIS, and is the period an applicant should use for planning purposes. APHIS shall make every attempt to complete its final review in less than 120 days. One hundred and twenty days will also allow APHIS to schedule an inspection of the site where the release is to occur prior to the issuance of a permit, as provided for in new § 340.3(d). It should be further noted that § 340.3(b) of the final rule is being revised to indicate that APHIS will complete its initial review within 30 days of receipt and shall advise the responsible individual if any additional information is needed within 30 days of receipt of the application.

APHIS disagrees with the commenter who suggested that a 14-day review period would be a sufficient period to process an application for a permit for interstate movement. As explained in more detail below, because of the need to consult with State officials and possibly to conduct an inspection of the contained facility where the regulated article is to be stored, APHIS has amended the final rule in § 340.3(b) to provide for a 60-day review period. For the review of applications for interstate movement or importation into a contained facility, APHIS will, however, complete its initial review within 15 days of receipt and advise the responsible individual if additional information is required. It should also be noted that 60 days is the *maximum* time USDA will take to review a complete permit application for interstate movement or importation to a contained facility and is the period an applicant should use for planning purposes. In all possible cases, APHIS will try to complete its final review in less than 60 days.

Data Required in an Application

27. One commenter noted that a significant amount of genetic information is required in advance of approval of experimentation. The commenter noted that the level of documentation required by these regulations is usually generated as a result of the research.

As revised, the final rule calls for less data in an application for a limited permit for interstate movement or importation than must be submitted in an application for environmental release. APHIS believes that the data that is required for an application for environmental release should have been obtained before release is requested, and can be obtained from the scientific literature and/or by doing research within a contained facility.

28. One commenter indicated that there is no need for APHIS to require extensive documentation on proposed experiments after the work has been approved elsewhere. The commenter suggested that documentation of other approvals, a brief description of the materials, and a statement of the level of containment should be enough to quickly be granted a permit to receive cultures that are to be used in a contained facility.

APHIS believes that the provisions of the final rule which provide for the issuance of a limited permit for interstate movement of a regulated article into a contained facility address many of the concerns raised by the commenter. As revised, APHIS will issue limited permits for interstate movement in less time by requiring less data than a permit for release into the environment.

Other commenters argued that the proposed regulations were too restrictive as they pertained to the interstate movement of low risk genetically engineered organisms. One commenter indicated that prior approval should not have to be obtained for the interstate movement of organisms shipped between laboratories which comply with NIH containment guidelines. The commenter argued that in such situations a simple notification to USDA pertaining to the movement of such organisms would suffice. These commenters did not present specific examples of the types of organisms and under what conditions certain organisms would not pose a risk of plant pest dissemination.

It appears that there are circumstances under which certain genetically engineered organisms such as those employed as "libraries" or biological containers can be moved interstate between contained facilities under conditions which would not present a risk of plant pest dissemination, and for which no permit would be required. It appears that such organisms are *E. coli* K-12 or other bacterial strains with similar characteristics, containing genetic material from any plant pest, except when such genetic material contains genes which code for: substances toxic to plants and organisms in the agro-ecosystem; or substances influencing plant growth; or genes for disease susceptability; or substances or characteristics associated with resistance to pesticides.

Likewise, a unique synthetic nucleotide sequence added as a "marker" for identification of a specific microorganism, when constructed to not constitute an open reading frame in any register, also poses no risk and is completely benign.

In accordance with notice provisions of the Administrative Procedure Act, APHIS intends to publish a proposed rule in the Federal Register within the next 30 days which would amend Part 340 to include these exclusions.

The fact that APHIS intends to publish a document which would propose to make certain changes to the final rule, shortly after its publication, reflects APHIS' belief that the regulations should be malleable and keep pace with the scientific "state of the art." It is anticipated that the APHIS regulations will parallel the NIH Guidelines in the sense that these regulations will continue to evolve and be updated as experience is gained and more information becomes available on the plant pest risk presented by the introduction of genetically engineered organisms. In short, APHIS believes that when it can be shown that the interstate movement between contained facilities of certain organisms does not present a risk of plant pest introduction or dissemination, then the regulations should be amended to exclude such movement from the permit requirements.

Lastly, to facilitate receipt of current data relative to the plant pest status of certain organisms from outside sources, APHIS has included the petition process in § 340.4 of the final rule.

Permit Processing Procedures

29. Section 340.3(b) of the final rule is a new section and is entitled, "Permit for release into the environment." If an application for environmental release is complete when received, APHIS shall notify the responsible individual of the date of receipt of the application for purposes of advising the applicant when the 120 day review period commenced. If an application is not complete, APHIS will advise the responsible individual what additional information must be submitted and shall commence the 120 day review period upon the receipt of the additional information, assuming the

additional data requested is adequate. When it is determined that an application is complete, APHIS shall submit to the State department of agriculture where the release is planned, a copy of its initial review and a copy of the application marked "CBI Deleted" or "No CBI" for State notification and review. Pursuant to APHIS' CBI Policy Statement of September 23, 1985 (50 FR 38561–38563), the requirements of Section VIII(b) must be complied with by a State prior to disclosure by APHIS to the State of CBI material. This section requires that the request be for an official purpose; that the requester have security procedures equivalent to those of APHIS; and that the person submitting the material determined by APHIS to be CBI be notified of the request prior to any disclosure.

An application for release into the environment must include the information required by § 340.3(b)(1)–(14). These are the same 14 data elements that appeared in the proposed regulations under § 340.3(a).

30. Section 340.3(c) of the final rule is a new section and is entitled, "Limited permits for the interstate movement or importation of a regulated article." This section provides for a 60 day review period with an initial review being performed by APHIS within 15 days of receipt of an application. Like an application for release into the environment, if an application is incomplete and additional information must be requested, APHIS will commence the 60 day review period upon receipt of the additional information. Section 340.3(c) of the final rule also provides that when APHIS determines that an application is complete, APHIS shall submit a copy of its initial review and the "CBI Deleted" or "No CBI" copy of the application to the State department of agriculture located in the State of destination of the regulated article, for State notification and review of the application.

State Involvement in the Review Process

31. Several comments were received from State departments of agriculture concerning the need for State involvement and participation when APHIS is deciding whether to issue a permit for release into the environment. A comment from the State of New Mexico indicated that notification of the State where release will be accomplished is necessary to minimize last minute complications. The State of California indicated that it has regulations that mandate certain review procedures prior to the release of certain genetically engineered organisms into the environment, and that APHIS' permit application for the introduction of genetically engineered organisms contains no provisions for State recommendations on the application. The State of North Carolina further indicated that the State where a person intends to release a regulated article should be given an opportunity to review the application, and that the State should be notified of any exemptions that may be granted, or if a permit is withdrawn.

APHIS agrees with these commenters that State notification and review of an application for the introduction of a regulated article is essential. To ensure that the affected State has been notified and has an opportunity to review a permit application for release or interstate movement or importation, APHIS has modified §§ 340.3(b) and (c) to include provisions that call for State notification and review of a permit application. These provisions which ensure State involvement and participation in the permitting process for genetically engineered organisms is totally consistent with existing procedures for the issuance of a permit for the movement of plant pests under 7 CFR 330.200. It is envisioned that State regulatory officials will play a significant role in providing site specific and other environmental and ecological data on the location where a genetically engineered organism is to be released, and otherwise assist in the enforcement of the Federal regulations, on a cooperative basis.

Provisions for the Issuance of a Single Permit for Multiple Interstate Movements

32. New § 340.3(c)(1) provides that the responsible person may apply for a single limited permit that would be valid for the interstate movement of multiple regulated articles moving between contained facilities in lieu of having to submit an application for each individual interstate movement. Such a limited permit for interstate movement would be valid for one year from the date of issuance. The purpose of this provision is to eliminate the need for a person to have to go to APHIS for approval each time the person proposes to ship a regulated article, when this information can be made available to APHIS in advance of the shipments, all at one time. APHIS has added provisions allowing for multiple shipments to multiple locations under a single limited permit in response to comments that it would be too burdensome to require a person to submit a new application for each new shipment. New § 340.3(c)(1) further provides that a limited permit for interstate movement of a regulated article shall only be valid for the movement of those regulated articles moving between those locations specified in the application. If a person seeks to move regulated articles other than those specified in the application or to locations other than those specified in the application, a supplemental application must be submitted to APHIS.

Section 340.3(c)(1) of the final rule further provides that the responsible person shipping a regulated article interstate shall keep records for one year demonstrating that the regulated article reached its intended destination. The purpose of this requirement is for the shipper of the regulated article and APHIS to be able to verify that the regulated article, in fact, reached its intended destination, and to provide the capacity to trace a regulated article in the event it is delivered to the wrong location. This provision can be satisfied when using the mail by sending a regulated article, "certified mail, return receipt requested," or by using a carrier that requires the consignee sign for the delivery. If a person does not use the mail or a carrier to deliver a regulated article, then the consignee should keep a log of when the regulated article is received, and a duplicate copy of the log should be maintained by the responsible individual. This section also requires that no person move a regulated article interstate unless the number of the limited permit appears on the outside of the shipping container.

A person must submit data required by §§340.3(b) (1), (2), (4), (8), (7), (9), and (11–14) in an application for a permit for multiple interstate movements. This is the same information that would have to be submitted in an application for a limited permit for a single interstate movement. This data would provide APHIS with necessary information about the nature of the regulated article(s), the method of movement, and how it shall be contained during movement and at the article's destination(s). Such information will enable APHIS to decide whether or not a permit can be issued. If a permit is issued, such data will be used in determining what conditions, if any, should be imposed as part of the permit to eliminate or reduce the possibility of dissemination of a plant pest.

Limited Permits for Importation

33. New § 340.3(c)(2) of the final rule provides that the responsible person seeking a permit for the importation of a regulated article to a contained facility must submit an application for a permit

at least 60 days prior to the importation of *each shipment* of regulated articles.

Unlike a limited permit for interstate movement, APHIS is requiring that a person submit a separate application for each importation of regulated articles rather than issuing a "single" permit for importation that would be valid for multiple importations for a specified period.

APHIS has traditionally allowed persons moving regulated articles interstate to do so repeatedly under the provisions of a single limited permit, for movement to specified destinations for utilization or processing. Such a system would not be practicable for the importation of regulated articles because the entry status of many imported articles frequently changes depending on the plant pest status of the article's country of origin. Because the entry status of a regulated article is subject to change, APHIS needs to review each permit application for importation prior to importation so that a decision whether to allow importation can be made on a case-by-case basis.

APHIS anticipates that in many cases, a request for the renewal of a limited permit for importation can be processed in less than 60 days. APHIS has added the following new footnote 7 to § 340.3 (c)(2) to reflect this fact.

Renewals may receive shorter review. In the case of a renewal for a limited permit for importation that was issued less than one year earlier, APHIS will notify the responsible person within 15 days that either: (1) The renewal permit is approved or (2) that a 60 day review period is necessary because the conditions of the original permit have changed.

APHIS is also requiring that the responsible person importing a regulated article keep records for one year that demonstrate that the regulated article arrived at its intended destination. The one year recordkeeping requirement is consistent with the recordkeeping requirement for limited permits for interstate movement. A person must submit data required by §§ 340.3(b)(1),(2),(4),(6),(7),(9), and (11)–(14) in an application for a limited permit for importation. This is the same data that must be submitted in an application for a limited permit to move a regulated article interstate. APHIS believes that such data will enable it to properly evaluate the risk of allowing the regulated article to be imported. This data will provide APHIS with necessary information about the country of origin of the regulated article, the nature of the regulated article, the method of movement, and how it shall be contained during movement and at its final destination. As with limited permits for interstate movement, because the regulated article is moving under containment into a contained facility, APHIS is requiring that the same data be submitted in an application to import the regulated article as is required in an application for interstate movement.

Certificate of Exemption/Courtesy Permits

34. Six comments were received on § 340.4 of the proposed regulation entitled, "Certificate of Exemption." Several commenters suggested that the term "exemption" is not appropriate because it implies that APHIS is exempting the introduction of a regulated organisms from the provisions of the regulation, rather than providing an indication that the organism was never subject to the regulation to begin with. These commenters suggested that the appropriate name for such a document should be a "courtesy permit," as found in 7 CFR 330.208. One commenter suggested that a certificate of exemption be issued in situations where a regulated article is biologically contained.

APHIS agrees with commenters that argued the name "certificate of exemption" is a misnomer, and has changed the name of the document that will be issued to "courtesy permit." APHIS will issue a courtesy permit under the same circumstances that were proposed for the issuance of a "certificate of exemption," i.e., the organism was never subject to regulation under Part 340, but is similar to other organisms regulated under Part 340.

APHIS also added new § 340.3(h)(3) which indicates that a courtesy permit will be issued within 60 days from the receipt of a complete application, or the applicant will be advised that a permit is required under § 340.3(b) or (c). APHIS will conduct its initial review of a courtesy permit application within 15 days of receipt of a complete application and advise the applicant within this period if any additional information is required. It should be noted that 60 days is the maximum time it will take for the issuance of a courtesy permit, and that every effort will be made to issue such permits in less than 60 days.

Since courtesy permits are issued for organisms which are not regulated articles, the issue of containment, whether biological or physical, is not material.

35. One commenter believed that a person would be required to obtain a "certificate of exemption" (now courtesy permit) when organisms are produced through classical genetics.

APHIS wishes to stress that a courtesy permit is an *option* that an applicant may seek if it believes that such a permit would facilitate the movement of an organism through a USDA port of entry, because the movement might otherwise be impeded because of its similarity to a regulated article.

Lastly, one commenter suggested that a certificate of exemption should be extended to those genetically engineered organisms otherwise subject to regulation under Part 340, that can be documented not to be plant pests.

In such cases, APHIS would issue a permit without conditions (restrictions) for the introduction of the regulated article.

The preceding discussion on APHIS permits can be summarized as follows:

APHIS PERMITS FOR THE INTRODUCTION OF A REGULATED ARTICLE[1]

Type of permit	Application elements	USDA review period	USDA action	State notification and review required
Environmental release	§ 340.3(b)(1)–(14)	120 days (maximum time from receipt of complete application;[1] initial review within 30 days).	Issue permit with conditions; request additional data; or deny permit with reasons.	Yes.
Limited Permit for Interstate Movement or Importation into a Contained Facility.	§ 340.3(b) (1), (2), (4), (6), (7), (9), (11)–(14).	60 days (maximum time from receipt of complete application; initial review within 15 days).	Same as above	Yes.

APHIS PERMITS FOR THE INTRODUCTION OF A REGULATED ARTICLE[1]—Continued

Type of permit	Application elements	USDA review period	USDA action	State notification and review required
Courtesy Permit[1] (not required; may be sought at the option of an applicant; organism not a regulated article).	§340.3(b) (1), (2), (5), (7) and statement why not a regulated article.	60 days with initial review within 15 days.	Issue courtesy permit; request additional data; or advise applicant that another permit is required.	No (if courtesy permit issued). Yes (if another permit issued).

[1] The 120 day review period would be extended if preparation of an environmental impact statement was required.

Need for Additional Safeguards

38. Three comments were received on the need for additional safeguards to be added to the rule. One commenter indicated that the proposed regulations did not contain the safeguards already present in 7 CFR 330.202(b) applicable to the movement of plant pests. The commenter noted such provisions allows USDA to inspect at its discretion, any site or premises prior to the issuance of a permit, to determine the adequacy of the site or premises for purposes of containment.

APHIS agrees with the commenter and believes that the final rule should contain provisions giving APHIS the option to conduct a site or premises inspection prior to the issuance of a permit. Accordingly, APHIS has added new § 340.3(d) entitled, "Premises inspection," which is consistent with 7 CFR 330.202(b) of its existing plant pest regulations. Section 340.3(d) provides that an inspector may inspect the site or facility where regulated articles are proposed to be released or contained under permit.

This section further provides that failure to allow the inspection of a premises prior to the issuance of an environmental release or limited permit shall be grounded for the denial of the permit.

37. Other commenters suggested that USDA publish guidelines for academic investigators that would be useful in determining what constitutes a pathogenic or environmental hazard, and recommendations for commensurate containment levels. One commenter further suggested that APHIS publish a laboratory safety monograph which addresses feasible greenhouse containment, and construction and utilization of growth chambers. Another commenter suggested that USDA include in its regulations minimal safety precautions for biotechnology research. The commenter further noted that not all personnel have the desirable training in anti-contamination and containment techniques.

APHIS believes that it would be beyond the scope of the regulations to include minimal safety precautions for biotechnology research. These comments pertain to worker safety and do not address the issue of plant pest dissemination and establishment. APHIS believes that such information should be made available by other Federal agencies whose responsibility is to regulate Federally funded research or worker safety, e.g., the National Institutes of Health, the Science and Education Administration of USDA, or the Occupational Safety and Health Administration (OSHA).

For reasons discussed in paragraph 17, APHIS does not believe the issuance of a monograph for greenhouse containment is appropriate because of the need to make such determinations on a case-by-case basis.

Standard Permit Conditions

38. Several commenters objected to the wording of some of the standard permit conditions. These commenters argued that the phrase "as determined necessary by the Deputy Administrator" is vague and open-ended.

In an attempt to provide more specificity to the standard permit conditions, APHIS has moved the phrase "as determined necessary by the Deputy Administrator" from the conditions in §§ 340.3(f) (1) and (2) and has inserted the phrase, "in a manner so as to prevent the establishment and dissemination of plant pests." APHIS believes this change makes these conditions more specific.

Sections 340.3(f) (7) and (8) still retain the phrase, "as determined necessary by the Deputy Administrator." The language in § 340.3(7) gives APHIS the authority to specify in a permit any special conditions that might be deemed necessary to ensure the regulated article will not be accidentally released or that there will not be an unauthorized release. APHIS believes that such determinations can only be made on a case-by-case basis, and that retention of this phrase gives APHIS the flexibility need to ensure against an accidental or unauthorized released of the regulated article.

Section 340.3(f)(8) provides that a regulated article shall be subject to the application of remedial measures (including disposal) determined by the Deputy Administrator to be necessary to prevent the spread of plant pests. Such authority would only be exercised in the event of an accidental release of the regulated article, and gives APHIS the necessary authority to prevent the dissemination of plant pests. Such emergency authority is found in 7 U.S.C. 150dd of the FPPA.

APHIS has revised § 340.3(f)(9) to now read, "a person who has been issued a permit shall submit to Plant Protection and Quarantine monitoring reports on the performance characteristics of the regulated article in accordance with any monitoring reporting requirements that may be specified in a permit. This condition previously specified that such reports would have to be submitted, "as deemed necessary by the Deputy Administrator." The decision to require the submission of monitoring reports will be made on a case-by-case basis, and will depend on the nature of the regulated article. Monitoring reports will not be required of all permittees.

39. Six commenters objected to the time periods for reporting specified events to APHIS (i.e., unauthorized release (24 hours)), characteristics substantially different from those in an application (5 working days), and death of the regulated article (5 working days). Several commenters also objected to having to report the death of the regulated article, believing that death is not an unusual occurrence. One commenter objected to the fact that oral notification was required immediately, and, in every case, followed by the submission of written notification. In response to these comments, APHIS has made the following changes to the reporting requirements in § 340.3(f)(10).

Oral reporting to APHIS is now only required in the event of any accidental or unauthorized release. Because of the potential consequences of such an event, APHIS believes that such

occurrence must be orally reported, immediately upon discovery, and in writing within 24 hours. If immediate oral notification is impossible, then reporting should occur on the first working day after discovery of the release. APHIS has eliminated the requirement of oral notification for all reportable events other than unauthorized or accidental release.

40. One commenter suggested that the rule should vary the time within which an accidental or unauthorized release must be reported, depending on the nature of the regulated article.

While not all regulated articles present the same risk of plant pest dissemination, APHIS believes that in the event of an unauthorized or accidental release, it needs to know about such events as quickly as possible and that reporting times should be uniform (24 hours) regardless of the nature of the regulated article.

41. In response to several comments, APHIS has eliminated the requirement of having to report the death of a regulated article in proposed § 340.3(c)(10)(iii). Under § 340.3(f)(10)(ii) of the final rule, a person need only report in writing, as soon as possible, but not later than 5 working days, if the regulated article or associated host organism is found to have characteristics substantially different from those listed in the permit application or suffers any unusual occurrence (excessive mortality or morbidity or an unanticipated effect on non-target organisms). APHIS believes that the death of a regulated article, as discussed above, should not be a reportable event.

APHIS believes that, as modified, having to report excessive mortality or morbidity or an unanticipated effect on a non-target organism as soon as possible but not later than 5 working days, is a reasonable requirement. APHIS believes that this requirement will advise the Agency of any disease or pest that may be of significance.

It should be noted that APHIS has added the phrase "as soon as possible" to clarify the agency's intent that the reporting should be prompt. However, APHIS has not changed the requirement which appeared in the proposed regulations that the reporting must not occur later than 5 working days from the observance of such events.

Denial of a Permit

APHIS, to fully inform permittees of their appeal rights, has included provisions in §§ 340.3(e) and (g) which provide appeal provisions in the event a permit is denied.

Petition To Amend the List of Organisms (§ 340.4)

42. Several commenters suggested that USDA should include a mechanism which would allow persons to petition for the "delisting" or removal of organisms from the list of organisms in § 340.2 of the final rule, if it could be demonstrated that such organisms are not plant pests. Other commenters indicated that USDA should include a mechanism that would allow a person to seek the addition of organisms to the list, if it could be shown that such organisms were plant pests.

USDA agrees with the commenters and has added a new § 340.4 to the final rule, entitled "Petition to Amend the List of Organisms." USDA believes that the petition mechanism will afford interested persons the opportunity to readily bring information to USDA's attention, as new information becomes available about existing or newly discovered organisms. The petition process in § 340.4 is in accord with section 4(e) of the Administrative Procedure Act (5 U.S.C. 553(e)) for the issuance, amendment, or repeal of a rule and with USDA's Departmental Proceedings in 7 CFR 1.28.

Under § 340.4(a) of the final rule, any person may submit a petition to the Deputy Administrator of Plant Protection and Quarantine to amend the list or organisms in § 340.2 by adding or removing any genus, species, or subspecies. Section 340.4(a) further provides that a petitioner may supplement, amend, or withdraw a petition, in writing, without prior approval of the Deputy Administrator and without prejudice to resubmission at any time, until the Deputy Administrator rules on the petition.

Section 340.4(b) specifies the submission procedures and format of a petition. This section requires that a petitioner provide two copies of a petition to the Deputy Administrator in care of the Director of the Biotechnology and Environmental Coordination Staff.

Section 340.4(b) also specifies what must be included in the "Statement of Grounds" of the petition. A person must include a full statement explaining the factual grounds why the genus, species, or subspecies to be added to § 340.2 is a plant pest or why there is reason to believe the genus, species, or subspecies is a plant pest. In the case of a petition to remove a genus, species, or subspecies from the list, a person must include a full statement explaining why the genus, species, or subspecies is not a plant pest or why there is no reason to believe the genus, species, or subspecies is not a plant pest. The petition should include copies of scientific literature which the petition is relying upon, copies of unpublished studies, or date from tests performed. Because the petition and any accompanying data will be made available for public inspection, the petition should not include trade secret or confidential business information.

A person must also include in the "Statement of Grounds" representative information known to the petitioner which would be unfavorable to a petition to add or remove organisms. Section 340.4(b) also requires that a petitioner sign a short certification that must be included as part of the petition.

Section 340.4(c) specifies the administrative action that will be taken on a petition. Under § 340.4(c), a petition which appears to be complete will be filed by the Director of the Biotechnology and Environmental Coordination Staff, stamped with the date of filing, and assigned a docket number. The Director of the Biotechnology and Environmental Coordination Staff will notify the petitioner in writing of the filing and the docket number of the petition. If a petition is incomplete, the petitioner shall be sent a notice indicating how the petition is deficient.

After a complete petition is filed, USDA shall publish a proposal in the **Federal Register** to amend § 340.2 and soliciting comments thereon from the public. Any written comments submitted shall become part of the docket file. The Deputy Administrator shall furnish a written response to each petitioner within 180 days of the receipt of the petition. The decision shall be placed in the public docket file in the offices of the Biotechnology and Environmental Coordination Staff.

The response will either: (1) Approve the petition in whole or in part, in which case the Deputy Administrator shall concurrently take appropriate action (publication of a document in the **Federal Register** amending § 340.2 of this part); or (2) deny the petition in whole or in part.

APHIS has chosen 180 days as the time period in which to respond to a petition for the following reasons: (1) A 180 day review period would provide APHIS reviewers sufficient time to perform thorough and comprehensive research on the material presented in a petition and to consult with other scientists at other institutions both domestically and internationally; (2) a 180 day review period provides APHIS with sufficient time to schedule public hearings during the petition process should that be necessary, and (3) a 180

day review period is consistent with the petition procedures utilized by other Federal agencies, namely, the Food and Drug Administration in their regulations in 21 CFR 10.30.

Container Requirements (§ 340.6)

43. Eight comments were received on the proposed container requirements in § 340.6 of the regulations. The commenters generally expressed the view that the container requirements were overly stringent and too restrictive, or in other cases inappropriate.

One commenter indicated that to assume that an organism is dangerous simply because it has been genetically modified is not justified. Another commenter indicated that in certain instances one may wish to carry plant seedlings a short distance across a State line in an open flat in a car. The commenter further indicated that in such an instance, there would be essentially no chance of dispersal of the plant since it would be devoid of any reproductive parts, and presumably all plant parts could be collected and accounted for in case of an accident.

USDA disagrees with the comment that a presumption exists that an organism is dangerous because it has been genetically modified. Consistent with stated USDA policy, the final rule does not regulate an organism because of the process by which it is modified. USDA believes that if a person is seeking to introduce an organism that is engineered from organisms which are known plant pests, then certain precautions are necessary. One precaution that must be taken is that until the plant pest status of the organism is established, special container requirements are required. The container requirements set forth in the final rule are no more stringent than what would be required for the movement of plant pests under permit in 7 CFR 330.200. However, USDA agrees with the commenter that argued that for certain organisms and in certain instances the container requirements may be inappropriate due to unique circumstances (the volume, nature, or life stage of the regulated article).

In order to remedy this situation on a case-by-case basis, APHIS has included a procedure whereby a person seeking to move a regulated article may seek a variance from the container requirements if the responsible individual believes the container requirements are inappropriate.

Section 340.6(b) of the final rule entitled, "Request for a variance from container requirements" provides that a person may submit a short statement describing why the applicable container requirements are inappropriate for the regulated article to be moved and what the individual would use in lieu thereof. USDA shall advise the responsible individual in writing at the time a permit is granted on the individual's request for a variance.

Cost of Preparing a Permit Application

Twenty comments were received on the APHIS analysis made pursuant to E.O. 12291 on the economic impact of the regulations. APHIS stated that it anticipated the cost of preparing a permit application to be not greater than $5,000 per application. Many of these commenters erroneously interpreted the statement to mean the APHIS would charge applicants not more than $5,000 as the fee for processing permit applications.

APHIS wishes to explain the $5,000 represented the maximum *in-house cost* to an applicant of submitting an application for a permit to APHIS. The $5,000 estimated cost was based on the salary of a Ph.D. researcher earning $60,000 per year. It was estimated that it would take approximately two weeks to prepare an application. The $5,000 figure also includes the cost of clerical support and reproduction costs. With the exception of reproduction and postage or handling costs, these costs are ordinary salary costs that must be paid regardless of whether a person is submitting a permit application to APHIS. Five thousand dollars for the most part represents the upper limit of the in-house costs. APHIS believes that in many cases, the cost will be significantly less than $5,000. It should be noted that one producer of genetically engineered organisms indicated that the $5,000 figure was accurate based on the cost of submitting an application for the field testing of a genetically engineered organism.

It should be further noted that under the final rule the $5,000 figure is only applicable to the cost of preparing an application for a permit for release into the environment. An application for a limited permit for the interstate movement or importation of a regulated article into a contained facility requires the submission of less data, and the time and cost required to prepare such an application should be less than $5,000.

Comments Concerning Joint Jurisdiction

Several comments were received on the issue of overlapping jurisdiction between USDA and EPA. Dual or redundant reviews of the same organism or product were mentioned as an unwelcome possibility.

During the months since the "Coordinated Framework" was first published as a proposed policy by the OSTP and Federal agencies in December 1984 (49 FR 50856–50907) the components of EPA and USDA that have jurisdiction in the same area have been in communication on a regular basis. USDA through its Biotechnology and Environmental Coordination Staff and EPA through its Office of Toxic Substances and Office of Pesticide Programs have identified principal liaisons who have the responsibility to share information, coordinate data requests, and keep one another informed of communications with submitters. These individuals will ensure that data requests are not duplicated.

Compliance With the National Environmental Policy Act

APHIS indicated in its proposed regulations at 51 FR 23359 on June 26, 1986, that the issuance of all permits for the introduction of a genetically engineered organism would be in accordance with National Environmental Policy Act (NEPA), USDA regulations, and APHIS Guidelines implementing NEPA.

APHIS shall prepare environmental assessments and, where necessary, environmental impact statements prior to issuing a permit for the release into the environment of a regulated article. The D.C. Circuit's decision in *FET v. Heckler*, stated that "NEPA requires an agency to evaluate the environmental effects of its action at the point of commitment." 756 F.2d 143 (D.C. Cir. 1985) With regard to this final rule, APHIS has concluded that the "point of commitment" occurs when the agency takes action on each individual application to issue a permit for the release into the environment of a genetically engineered organism.

The final rule does not irrevocably commit APHIS to any decision concerning issuance of any permits for release. APHIS retains the authority to grant or deny a permit for release on a case by case basis. However, APHIS has prepared a special environmental assessment on the effect of these regulations.

The special environmental assessment for the final rule discusses alternatives that were considered in lieu of promulgation of this rule and is available from the person listed under "FOR FURTHER INFORMATION CONTACT."

Editorial Changes

APHIS has also made minor editorial changes, where necessary.

Executive Order 12291 and Regulatory Flexibility Act

This final rule is issued in conformance with Executive Order 12291 and has been determined to be not a "major rule." Based on information compiled by the Department, it has been determined that the proposed rule will not have a significant effect on the economy; will not cause a major increase in costs or prices for consumers, individual industries, Federal, State, or local government agencies, or geographic regions; and would not have a significant adverse effect on competition, employment, investment, productivity, innovation, or on the ability of United States-based enterprises to compete with foreign-based enterprises in domestic or export markets.

As explained above, regulations regulate the introduction (importation, interstate movement, and release into the environment) of organisms and products altered or produced through genetic engineering which are plant pests or which there is reason to believe are plant pests. Such organisms and products are deemed regulated articles for which either a limited or environmental release permit would have to be obtained prior to its introduction.

It is anticipated that the cost of preparing a permit application for the release into the environment of a regulated article will be no more than $5.00 per application. The cost of preparing an application for a limited permit which requires less data than an environmental release permit should be less than $5,000. The required information about the organism, and the way it was altered or produced should be available from documents pertaining to the research and development of the regulated article. Thus, a person seeking to obtain a permit should not have to generate any new data, but rather submit to APHIS, what should be, existing data. The $5,000 estimated cost is based on the salaries of a Ph.D. researcher and the necessary clerical staff working for approximately 2 weeks in preparing an application for a permit for environmental release. During the first year, the Department does not expect to receive more than 50 applications for release into the environment. Most other costs associated with complying with the regulations, e.g., container requirements, are merely incidental to a person complying with sound laboratory and research practices. The only other costs associated with complying with the regulations would arise if a supplemental report were required, e.g., an accidental or unauthorized release of a regulated article, the regulated article is found to have substantially different characteristics than those listed in the application, or if APHIS otherwise believes monitoring reports are required. It is anticipated that the cost of such reports in most instances would be minimal.

APHIS is requiring that an application for a permit be submitted 120 days prior to the time a person seeks to release a regulated article into the environment. APHIS believes that the 120 day time period required to process a permit application will not be an unreasonable delay in the marketing of organisms or products subject to regulations under Part 340. It is anticipated that if USDA receives only 50 applications the first year for the release into the environment, the average time to process any application will be considerably less than the maximum processing periods of 120 days. APHIS does not believe that the applications will come all at once. In the short term, we anticipate receiving 50 applications the first year, growing to perhaps 3,000 by 1989. The experience gained during the first year should help expedite the review of future applications. As more applications are processed, shorter review times could be achieved through the use of data previously submitted.

Since the timing of when to submit an application to USDA is left to an applicant, USDA believes that both large and small business entities will be able to incorporate the review period into their planning process so as not to disrupt the marketing of organisms or products that are subject to regulation.

Under the circumstances referred to above, the Administrator of the Animal and Plant Health Inspection Service has determined that this action would not have a significant economic impact on a substantial number of small entities.

Paperwork Reduction Act

Information collection requirements contained in this document have been approved by the Office of Management and Budget (OMB) under the provisions of the Paperwork Reduction Act (44 U.S.C. 3501 et seq.) and have been assigned OMB control number 0579-0085.

Executive Order 12372

This program/activity is listed in the Catalog of Federal Domestic Assistance under No. 10.025 and is subject to the provisions of Executive Order 12372 which requires intergovernmental consultation with State and local officials. (See 7 CFR Part 3015, Subpart V.)

List of Subjects

7 CFR Part 330

Customs duties and inspection, Garbage, Imports, Plant diseases, Plant pests, Plants (Agriculture), Quarantine, Soil, Stone and quarry products, Transportation.

7 CFR Part 340

Agricultural commodities, Biotechnology, Genetic engineering, Plant diseases, Plant pests, Plants (Agriculture), Quarantine, Transportation.

PART 330—FEDERAL PLANT PEST REGULATIONS; GENERAL; PLANT PESTS; SOIL, STONE AND QUARRY PRODUCTS; GARBAGE

Accordingly, 7 CFR Part 330 is amended to read as follows:

1. The authority citation for 7 CFR Part 330 is revised to read as follows:

Authority: 7 U.S.C. 147a, 150bb, 150dd-150ff, 161, 162, 450, 2260; 19 U.S.C. 1306; 21 U.S.C. 111, 114a; 31 U.S.C. 9701; 7 CFR 2.17, 2.51, and 371.2(c).

2. Paragraph (h) § 330.100 is revised to read as follows:

§ 330.100 Definitions.

* * * * *

(h)(1) *Plant pest.* Except for §§ 330.200 through 330.212, "Plant Pest" means any living stage of any insects, mites, nematodes, slugs, snails, protozoa, or other invertebrate animals, bacteria, fungi, other parasitic plants or reproductive parts thereof, viruses, or any organisms similar to or allied with any of the foregoing, or any infectious substances which can directly or indirectly injure or cause disease or damage in any plants or parts thereof, or any processed, manufactured, or other products of plants.

(2) *Plant pest.* For purposes of §§ 330.200 through 330.212, "Plant Pest" means any living stage of insects, mites, nematodes, slugs, snails, protozoa, or other invertebrate animals, bacteria, fungi, other parasitic plants or reproductive parts thereof, viruses, or any organisms similar to or allied with any of the foregoing, or any infectious substances of the aforementioned which are not genetically engineered as defined in 7 CFR 340.1 which can directly or indirectly injure or cause disease or damage in any plants or parts thereof, or any processed, manufactured, or other products of plants.

* * * * *

Accordingly, 7 CFR, Chapter III, is amended by adding Part 340 to read as follows:

PART 340—INTRODUCTION OF ORGANISMS AND PRODUCTS ALTERED OR PRODUCED THROUGH GENETIC ENGINEERING WHICH ARE PLANT PESTS OR WHICH THERE IS REASON TO BELIEVE ARE PLANT PESTS

Sec.

340.0 Restrictions on the introduction of regulated articles.
340.1 Definitions.
340.2 Groups of organisms which are or contain plant pests.
340.3 Permits for the introduction of a regulated article.
340.4 Petition to amend the list of organisms.
340.5 Marking and identity.
340.6 Container requirements for the movement of regulated articles.
340.7 Cost and charges.

Authority: 7 U.S.C. 150aa–150jj, 151–167, 1622n; 31 U.S.C. 9701; 7 CFR 2.17, 2.51, and 371.2(c).

§ 340.0 Restrictions on the introduction of regulated articles.

(a) No person shall introduce any regulated article unless: (1) Such introduction is authorized by a permit; and (2) such introduction is in conformity with all of the other applicable restrictions in this part.[1]

(b) Any regulated article introduced not in compliance with the requirements of this part shall be subject to the immediate application of such remedial measures or safeguards as an inspector determines necessary to prevent the introduction of such plant pests.[2]

[1] Part 340 regulates the introduction of organisms altered or produced through genetic engineering and their products which are plant pests or which there is reason to believe are plant pests. The introduction into the United States of such articles may be subject to other regulations promulgated under the Federal Plant Pest Act (7 U.S.C. 150aa *et seq.*), the Plant Quarantine Act (7 U.S.C. 151 *et seq.*), and the Federal Noxious Weed Act (7 U.S.C. 2801 *et seq.*) and found in 7 CFR Parts 319, 321, 330, and 360. For example under regulations promulgated in 7 CFR "Subpart-Nursery Stock" (7 CFR 319.37) a permit is required for the importation of certain classes of nursery stock whether genetically engineered or not. Thus, a person should consult those regulations prior to the importation of any nursery stock.

[2] Pursuant to section 106 of the Federal Plant Pest Act (7 U.S.C. 150dd) the Secretary of Agriculture is authorized to order prompt removal from the United States or to seize, quarantine, treat, apply other remedial measures to, destroy, or otherwise dispose of, in such manner as the Secretary deems appropriate, certain regulated articles which are believed to be infested or infected by or contain a plant pest.

§ 340.1 Definitions.

Terms used in the singular form in this part shall be construed as the plural, and vice versa, as the case may demand. The following terms, when used in this part, shall be construed, respectively, to mean:

Courtesy permit. A written permit issued by the Deputy Administrator in accordance with § 340.3(h) of this part.

Deputy Administrator. The Deputy Administrator for Plant Protection and Quarantine, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, or any other officer or employee of the Department to whom authority to act in his/her stead has been or may hereafter be delegated.

Donor organism. The organism from which genetic material is obtained for transfer to the recipient organism.

Environment. All the land, air, and water; and all living organisms in association with land, air and water.

Genetic engineering. The genetic modification of organisms by recombinant DNA techniques.

Inspector. Any employee of Plant Protection and Quarantine, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, or other person, authorized by the Deputy Administrator in accordance with law to enforce the provisions of this part.

Interstate. From any State into or through any other State.

Introduce or introduction. To move into or through the United States, to release into the environment, to move interstate, or any attempt thereat.

Move (moving, movement). To ship, offer for shipment, offer for entry, import, receive for transportation, carry, or otherwise transport or move, or allow to be moved into, through, or within the United States.

Organism. Any active, infective, or dormant stage or life form of an entity characterized as living, including vertebrate and invertebrate animals, plants, bacteria, fungi, mycoplasmas, mycoplasma-like organisms, as well as entities such as viroids, viruses, or any entity characterized as living, related to the foregoing.

Permit. A written permit issued by the Deputy Administrator for the introduction of a regulated article under conditions determined by the Deputy Administrator not to present a risk of plant pest introduction.

Person. Any individual, partnership, corporation, company, society, association, or other organized group.

Plant. Any living stage or form of any member of the plant kingdom [3] including, but not limited to, eukaryotic algae, mosses, club mosses, ferns, angiosperms, gymnosperms, and lichens (which contain algae) including any parts (e.g. pollen, seeds, cells, tubers, stems) thereof, and any cellular components (e.g. plasmids, ribosomes, etc.) thereof.

Plant pest. Any living stage (including active and dormant forms) of insects, mites, nematodes, slugs, snails, protozoa, or other invertebrate animals, bacteria, fungi, other parasitic plants or reproductive parts thereof; viruses; or any organisms similar to or allied with any of the foregoing; or any infectious agents or substances, which can directly or indirectly injure or cause disease or damage in or to any plants or parts thereof, or any processed, manufactured, or other products of plants.

Plant Protection and Quarantine. The organizational unit within the Animal and Plant Health Inspection Service, U.S. Department of Agriculture, delegated responsibility for enforcing provisions of the Plant Quarantine Act, the Federal Plant Pest Act, and related legislation, and quarantine and regulations promulgated thereunder.

Product. Anything made by or from, or derived from an organism, living or dead.

Recipient organism. The organism which receives genetic material from a donor organism.

Regulated article. Any organism which has been altered or produced through genetic engineering, if the donor organism, recipient organism, or vector or vector agent belongs to any genera or taxa designated in § 340.2 of this part and meets the definition of plant pest, or is an unclassified organism and/or an organism whose classification is unknown, or any product which contains such as organism, or any other organism or product altered or produced through genetic engineering which the Deputy Administrator determines is a plant pest or has reason to believe is a plant pest. Excluded are recipient microorganisms which are not plant pests and which have resulted from the addition of genetic material from a donor organism where the material is well characterized and contains only non-coding regulatory regions.

Release into the environment. The use of a regulated article outside the constraints of physical confinement that are found in a laboratory, contained

[3] The taxonomic scheme for the plant kingdom is that found in Synopsis and Classification of Living Organisms by S.P. Parker, McGraw Hill (1984).

greenhouse, or a fermenter or other contained structure.

Responsible person. The person who has control and will maintain control over the introduction of the regulated article and assure that all conditions contained in the permit and requirements in this part are complied with. A responsible person shall be a resident of the United States or designate an agent who is a resident of the United States.

Secretary. The Secretary of Agriculture, or any other officer or employee of the Department of Agriculture to whom authority to act in his/her stead has been or may hereafter be delegated.

State. Any State, the District of Columbia, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, the Virgin Islands of the United States, and any other Territories or Districts of the United States.

United States. All of the States.

Vector or vector agent. Organisms or objects used to transfer genetic material from the donor organism to the recipient organism.

Well-characterized and contains only non-coding regulatory regions (e.g. operators, promoters, origins of replication, terminators, and ribosome binding regions). The genetic material added to a microorganism in which the following can be documented about such genetic material: (a) The exact nucleotide base sequence of the regulatory region and any inserted flanking nucleotides; (b) The regulatory region and any inserted flanking nucleotides do not code for protein or peptide; and (c) The regulatory region solely controls the activity of other sequences that code for protein or peptide molecules or act as recognition sites for the initiation of nucleic acid or protein synthesis.

§ 340.2 Groups of organisms which are or contain plant pests.

The organisms that are or contain plant pests are included in the taxa or group of organisms contained in the following list. Within any taxonomic series included on the list, the lowest unit of classification actually listed is the taxon or group which may contain organisms which are regulated. Organisms belonging to all lower taxa contained within the group listed are included as organisms that may be or may contain plant pests, and are regulated *if they meet the definition of plant pest in § 340.1*[4]

[4] Any organism belonging to any taxa contained within any listed genera or taxa is only considered to be a plant pest if the organism "can directly or indirectly injure, or cause disease, or damage in any plants or parts thereof, or any processed, manufactured, or other products of plants." Thus a particular unlisted species within a listed genus would be deemed a plant pest for purposes of § 340.2, if the scientific literature refers to the organism as a cause of direct or indirect injury, disease, or damage to any plants, plant parts or products of plants. (If there is any question concerning the plant pest status of an organism belonging to any listed genera or taxa, the person proposing to introduce the organism in question should consult with APHIS to determine if the organism is subject to regulation.)

Note.—Any genetically engineered organism composed of DNA or RNA sequences, organelles, plasmids, parts, copies, and/or analogs, of or from any of the groups of organisms listed below shall be deemed a regulated article if it also meets the definition of plant pest in § 340.1.

GROUP

Viroids

Superkingdom Prokaryotae

Kingdom Virus

All members of groups containing plant viruses, and all other plant and insect viruses

Kingdom Monera

Division Bacteria

Family Pseudomonadaceae
- Genus Pseudomonas
- Genus Xanthomonas

Family Rhizobiaceae
- Genus Rhizobium
- Genus Bradyrhizobium
- Genus Agrobacterium
- Genus Phyllobacterium

Family Enterobacteriaceae
- Genus Erwinia

Family Streptomycetaceae
- Genus Streptomyces

Family Actinomycetaceae
- Genus Actinomyces

Coryneform group
- Genus Clavibacter
- Genus Arthrobacter
- Genus Curtobacterium
- Genus Corynebacteria

Gram-negative phloem-limited bacteria associated with plant diseases

Gram-negative xylem-limited bacteria associated with plant diseases

And all other bacteria associated with plant or insect diseases

Rickettsiaceae
- Rickettsial-like organisms associated with insect diseases

Class Mollicutes

Order Mycoplasmatales

Family Spiroplasmataceae
- Genus Spiroplasma

Mycoplasma-like organisms associated with plant diseases

Mycoplasma-like organisms associated with insect diseases

Superkingdom Eukaryotae

Kingdom Plantae

Subkingdom Thallobionta

Division Chlorophyta
- Genus Cephaleuros
- Genus Rhodochytrium
- Genus Phyllosiphon

Division Myxomycota

Class Plasmodiophoromycetes

Division Eumycota

Class Chytridiomycetes

Order Chytridiales

Class Oomycetes

Order Lagenidiales
Family Lagenidiaceae
Family Olpidiopsidaceae
Order Peronosporales
Family Albuginaceae
Family Peronosporaceae
Family Pythiaceae
Order Saprolegniales
Family Saprolegniaceae
Family Leptolegniellaceae

Class Zygomycetes

Order Mucorales
Family Choanephoraceae
Family Mucoraceae
Family Entomophthoraceae

Class Hemiascomycetes

Family Protomycetaceae
Family Taphrinaceae

Class Loculoascomycetes

Order Myriangiales
Family Elsinoeaceae
Family Myriangiaceae
Order Asterinales
Order Dothideales
Order Chaetothyriales
Order Hysteriales
Family Parmulariaceae
Family Phillipsiellaceae
Family Hysteriaceae
Order Pleosporales
Order Melanommatales

Class Plectomycetes

Order Eurotiales
Family Ophiostomataceae
Order Ascophaerales

Class Pyrenomycetes

Order Erysiphales
Order Meliolales
Order Xylariales
Order Diaporthales
Order Hypocreales
Order Clavicipitales

Class Discomycetes

Order Phacidiales
Order Helotiales
Family Ascocorticiceae
Family Hemiphacidiaceae
Family Dermataceae
Family Sclerotiniaceae
Order Cytarriales
Order Medeolariales
Order Pezziales
Family Sarcosomataceae
Family Sarcoscyphaceae

Class Teliomycetes

Class Phragmobasidiomycetes

Family Auriculariaceae
Family Ceratobasidiaceae

Class Hymenomycetes

Order Exobasidiales
Order Agaricales
Family Corticiaceae
Family Hymenochaetaceae
Family Echinodontiaceae
Family Fistulinaceae
Family Clavariaceae
Family Polyporaceae
Family Tricholomataceae

Class Hyphomycetes

Class Coelomycetes

And all other fungi associated with plant or insect diseases

Subkingdom Embryobionta

Note.—*Organisms listed in the Code of Federal Regulations as noxious weeds are regulated under the Federal Noxious Weed Act*

Division Magnoliophyta

Family Balanophoraceae—parasitic species
Family Cuscutaceae—parasitic species
Family Hydnoraceae—parasitic species
Family Krameriaceae—parasitic species
Family Lauraceae—parasitic species
  Genus Cassytha
Family Lennoaceae—parasitic species
Family Loranthaceae—parasitic species
Family Myzodendraceae—parasitic species
Family Olacaceae—parasitic species
Family Orobanchaceae—parasitic species
Family Rafflesiaceae—parasitic species
Family Santalaceae—parasitic species
Family Scrophulariaceae—parasitic species
  Genus Alectra
  Genus Bartsia
  Genus Buchnera
  Genus Buttonia
  Genus Castilleja
  Genus Centranthera
  Genus Cordylanthus
  Genus Dasistoma
  Genus Euphrasia
  Genus Gerardia
  Genus Harveya
  Genus Hyobanche
  Genus Lathraea
  Genus Melampyrum
  Genus Melasma
  Genus Orthantha
  Genus Orthocarpus
  Genus Pedicularis
  Genus Rhamphicarpa
  Genus Rhinanthus
  Genus Schwalbea
  Genus Seymeria
  Genus Siphonostegia
  Genus Sopubia
  Genus Striga
  Genus Tozzia
Family Viscaceae—parasitic species

Kingdom Animalia

Subkingdom Protozoa

  Genus Phytomonas

  And all Protozoa associated with insect diseases

Subkingdom Eumetazoa

Phylum Nemata

Class Secernentea

Order Tylenchida
Family Anguinidae
Family Belonolaimidae
Family Caloosiidae
Family Criconematidae
Family Dolichodoridae
Family Fergusobiidae
Family Hemicycliophoridae
Family Heteroderidae
Family Hoplolaimidae
Family Meloidogynidae
Family Nacobbidae
Family Neotylenchidae
Family Nothotylenchidae
Family Paratylenchidae
Family Pratylenchidae
Family Tylenchidae
Family Tylenchulidae
Order Aphelenchida
Family Aphelenchoididae

Class Adenophorea

Order Dorylaimida
Family Longidoridae
Family Trichodoridae

Phylum Mollusca

Class Gastropoda

Subclass Pulmonata
Order Basommatophora
  Superfamily Planorbacea
Order Stylommatophora
  Subfamily Strophocheilacea
Family Succineidae
  Superfamily Achatinacae
  Superfamily Arionacae
  Superfamily Limacacea
  Superfamily Helicacea
Order Systellommatophora
  Superfamily Veronicellacea

Phylum Arthropoda

Class Arachnida

Order Parasitiformes
  Suborder Mesostigmata
  Superfamily Ascoidea
  Superfamily Dermanyssoidea
Order Acariformes
  Suborder Prostigmata
  Superfamily Eriophyoidea
  Superfamily Tetranychoidea
  Superfamily Eupodoidea
  Superfamily Tydeoidea
  Superfamily Erythraenoidea
  Superfamily Trombidioidea
  Superfamily Hydryphantoidea
  Superfamily Tarsonemoidea
  Superfamily Pyemotoidea
Suborder Astigmata
  Superfamily Hemisarcoptoidea
  Superfamily Acaroidea

Class Diplopoda

Order Polydesmida

Class Insecta

Order Collembola
Family Sminthoridae
Order Isoptera
Order Thysanoptera
Order Orthoptera
Family Acrididae
Family Gryllidae
Family Gryllacrididae
Family Gryllotalpidae
Family Phasmatidae
Family Ronaleidae
Family Tettigoniidae
Family Tetrigidae
Order Hemiptera
Family Thaumastocoridae
Family Aradidae
  Superfamily Piesmatoidea
  Superfamily Lygaeoidea
  Superfamily Idiostoloidea
  Superfamily Coreoidea
  Superfamily Pentatomoidea
  Superfamily Pyrrhocoroidea
  Superfamily Tingoidea
  Superfamily Miroidea
Order Homoptera
Order Coleoptera
Family Anobiidae
Family Apionidae
Family Anthribidae
Family Bostrichidae
Family Brentidae
Family Bruchidae
Family Buprestidae
Family Byturidae
Family Cantharidae
Family Carabidae
Family Cerambycidae
Family Chrysomelidae
Family Coccinellidae
  Subfamily Epilachninae
Family Curculionidae
Family Dermestidae
Family Elateridae
Family Hydrophilidae
  Genus Helophorus
Family Lyctidae
Family Meloidae
Family Mordellidae
Family Platypodidae
Family Scarabaeidae
  Subfamily Melolonthinae
  Subfamily Rutelinae
  Subfamily Cetoniinae
  Subfamily Dynastinae
Family Scolytidae
Family Selbytidae
Family Tenebrionidae
Order Lepidoptera
Order Diptera
Family Agromyzidae
Family Anthomyiidae
Family Cecidomyiidae
Family Chloropidae
Family Ephydridae
Family Lonchaeidae
Family Muscidae
  Genus Atherigona
Family Otitidae
  Genus Euxesta
Family Syrphidae
Family Tephritidae
Family Tipulidae
Order Hymenoptera
Family Apidae
Family Cephidae
Family Chalcidae
Family Cynipidae
Family Eurytomidae
Family Formicidae
Family Pelidae
Family Siricidae
Family Tenthredinidae

Family Torymidae
Family Xylocopidae

Unclassified organisms and/or organisms whose classification is unknown.

§ 340.3 Permits for the introduction of a regulated article.

(a) *Application for permit.* Two copies of a written application for a permit to introduce a regulated article shall be submitted by the responsible person on an application form obtained from Plant Protection and Quarantine, to the Biological Assessment Support Staff (Biotech Unit), Plant Protection and Quarantine, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Federal Building, 6505 Belcrest Road, Hyattsville, Maryland 20782. If there are portions of the application deemed to contain trade secret or confidential business information (CBI), each page of the application containing such information should be marked "CBI Copy". In addition, those portions of the application which are deemed "CBI" shall be so designated. The second copy shall have all such CBI deleted and shall be marked on each page of the application where CBI was deleted, "CBI Deleted". If an application does not contain CBI then the first page of both copies shall be marked "No CBI".

(b) *Permit for release into the environment.* An application for the release into the environment of a regulated article shall be submitted at least 120 days in advance of the proposed release into the environment. An initial review shall be completed by Plant Protection and Quarantine within 30 days of the receipt of the application. If the application is complete, the responsible individual shall be notified of the date of receipt of the application for purposes of advising the applicant when the 120 day review period commenced.[5] If the application is not complete, the responsible individual will be advised what additional information must be submitted. Plant Protection and Quarantine shall commence the 120 day review period upon receipt of the additional information, assuming the additional information submitted is adequate. When it is determined that an application is complete, Plant Protection and Quarantine shall submit to the State department of agriculture of the State where the release is planned, a copy of the initial review and a copy of the application marked, "CBI Deleted", or "No CBI" for State notification and review. The application shall include the following information: [6]

(1) Name, title, address, telephone number, signature of the responsible person and type of permit requested (for importation, interstate movement, or release into the environment);

(2) All scientific, common, and trade names, and all designations necessary to identify the: Donor organism(s); recipient organism(s); vector or vector agent(s); constituent of each regulated article which is a product; and, regulated article;

(3) Names, addresses, and telephone numbers of the persons who developed and/or supplied the regulated article;

(4) A description of the means of movement (e.g., mail, common carrier, baggage, or handcarried (and by whom));

(5) A description of the anticipated or actual expression of the altered genetic material in the regulated article and how that expression differs from the expression in the non-modified parental organism (e.g., morphological or structural characteristics, physiological activities and processes, number of copies of inserted genetic material and the physical state of this material inside the recipient organism (integrated or extrachromosomal), products and secretions, growth characteristics);

(6) A detailed description of the molecular biology of the system (e.g., donor-recipient-vector) which is or will be used to produce the regulated article;

(7) Country and locality where the donor organism, recipient organism, vector or vector agent, and regulated article were collected, developed, and produced;

(8) A detailed description of the purpose for the introduction of the regulated article including a detailed description of the proposed experimental and/or production design;

(9) The quantity of the regulated article to be introduced and proposed schedule and number of introductions;

(10) A detailed description of the processes, procedures, and safeguards which have been used or will be used in the country of origin and in the United States to prevent contamination, release, and dissemination in the production of the: Donor organism; recipient organism; vector or vector agent; constituent of each regulated article which is a product; and regulated article;

(11) A detailed description of the intended destination (including final and all intermediate destinations), uses, and/or distribution of the regulated article (e.g., greenhouses, laboratory, or growth chamber location; field trial location; pilot project location; production, propagation, and manufacture location; proposed sale and distribution location);

(12) A detailed description of the proposed procedures, processes, and safeguards which will be used to prevent escape and dissemination of the regulated article at each of the intended destinations;

(13) A detailed description of any biological material (e.g., culture medium, or host material) accompanying the regulated article during movement; and

(14) A detailed description of the proposed method of final disposition of the regulated article.

(c) *Limited permits for interstate movement or importation of a regulated article.* An application for the interstate movement or importation of a regulated article shall be submitted at least 60 days in advance of the first proposed interstate movement and at least 60 days prior to each importation. An initial review shall be completed by Plant Protection and Quarantine within 15 days of the receipt of the application. If the application is complete, the responsible person shall be notified of the date of receipt of the application for purposes of advising the applicant when the 60 day review period commenced. If the application is not complete, the responsible person will be advised what additional information must be submitted. Plant Protection and Quarantine shall commence the 60 day review period upon receipt of the additional information, assuming the additional information submitted is adequate. When it is determined that an application is complete, Plant Protection and Quarantine shall submit to the State department of agriculture of the State of destination of the regulated article a copy of the initial review and the application marked, "CBI Deleted", or "No CBI" for State notification and review.

(1) *Limited permit for interstate movement.* The responsible person may apply for a single limited permit for the interstate movement of multiple regulated articles in lieu of submitting an application for each individual interstate movement. Each limited permit issued shall be numbered and shall be valid for one year from the date

[5] The 120 day review period would be extended if preparation of an environmental impact statement in addition to an environmental assessment was necessary.

[6] Application forms are available without charge from the Biological Assessment Support Staff, Plant Protection and Quarantine, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Federal Building, 6505 Belcrest Road, Hyattsville, Maryland 20782, or from local offices which are listed in telephone directories. A person should specify in requesting the application that the permit is for the introduction of a regulated article subject to regulation under Part 340.

of issuance. If a permit is sought for multiple interstate movements between contained facilities the responsible individual shall specify in the permit application all the regulated articles to be moved interstate: the origins and destinations of all proposed shipments: a detailed description of all the contained facilities where regulated articles will be utilized at destination: and a description of the containers that will be used to transport the regulated articles. A limited permit for interstate movement of a regulated article shall only be valid for the movement of those regulated articles moving between those locations specified in the application. If a person seeks to move regulated articles other than those specified in the application, or to a location other than those listed in the application, a supplemental application shall be submitted to Plant Protection and Quarantine. No person shall move a regulated article interstate unless the number of the limited permit appears on the outside of the shipping container. The responsible person shipping a regulated article interstate shall keep records for one year demonstrating that the regulated article arrived at its intended destination. The responsible person seeking a limited permit for interstate movement shall submit on an application form obtained from Plant Protection and Quarantine the data required by § 340.3(b)(1), (2), (4), (6), (7), (9), and (11)–(14).

(2) *Limited permit for importation.* The responsible person seeking a permit for the importation of a regulated article shall submit an application for a permit prior to the importation of *each* shipment of regulated articles. The responsible person importing a regulated article shall keep records for one year demonstrating that the regulated article arrived at its intended destination. The responsible person seeking a limited permit for importation shall submit on an application form obtained from Plant Protection and Quarantine data required by § 340.3(b)(1), (2), (4), (6), (7), (9), and (11)–(14).[1]

(d) *Premises inspection.* An inspector may inspect the site or facility where regulated articles are proposed, pursuant to a permit, to be released into the environment or contained after their interstate movement or importation. Failure to allow the inspection of a premises prior to the issuance of a permit or limited permit shall be grounds for the denial of the permit.

(e) *Administrative action on applications.* After receipt and review by Plant Protection and Quarantine of the application and the data submitted pursuant to paragraph (a) of this section, including any additional information requested by Plant Protection and Quarantine, a permit shall be granted or denied. If a permit is denied, the applicant shall be promptly informed of the reasons why the permit was denied and given the opportunity to appeal the denial in accordance with the provisions of paragraph (g) of this section. If a permit is granted, the permit will specify the applicable conditions for introduction of the regulated article under this part.

(f) *Permit conditions.* A person who is issued a permit and his/her employees or agents shall comply with the following conditions, and any supplemental conditions which shall be listed on the permit, as deemed by the Deputy Administrator to be necessary to prevent the dissemination and establishment of plant pests:

(1) The regulated article shall be maintained and disposed of (when necessary) in a manner so as to prevent the dissemination and establishment of plant pests.

(2) All packing material, shipping containers, and any other material accompanying the regulated article shall be treated or disposed of in such a manner so as to prevent the dissemination and establishment of plant pests.

(3) The regulated article shall be kept separate from other organisms, except as specifically allowed in the permit:

(4) The regulated article shall be maintained only in areas and premises specified in the permit:

(5) An inspector shall be allowed access, during regular business hours, to the place where the regulated article is located and to any records relating to the introduction of a regulated article:

(6) The regulated article shall, when possible, be kept identified with a label showing the name of the regulated article, and the date of importation:

(7) The regulated article shall be subject to the application of measures determined by the Deputy Administrator to be necessary to prevent the accidental or unauthorized release of the regulated article;

(8) The regulated article shall be subject to the application of remedial measures (including disposal) determined by the Deputy Administrator to be necessary to prevent the spread of plant pests:

(9) A person who has been issued a permit shall submit to Plant Protection and Quarantine monitoring reports on the performance characteristics of the regulated article, in accordance with any monitoring reporting requirements that may be specified in a permit:

(10) Plant Protection and Quarantine shall be notified within the time periods and manner specified below, in the event of the following occurrences:

(i) Orally notified immediately upon discovery and notify in writing within 24 hours in the event of any accidental or unauthorized release of the regulated article:

(ii) In writing as soon as possible but not later than within 5 working days if the regulated article or associated host organism is found to have characteristics substantially different from those listed in the application for a permit or suffers any unusual occurrence (excessive mortality or morbidity, or unanticipated effect on non-target organisms);

(11) A permittee or his/her agent and any person who seeks to import a regulated article into the United States shall:

(i) Import or offer the regulated article for entry only at a port of entry which is designated by an asterisk in 7 CFR 319.37–14(b);

(ii) Notify Plant Protection and Quarantine promptly upon arrival of any regulated article at a port of entry, of its arrival by such means as a manifest, customs entry document, commercial invoice, waybill, a broker's document, or a notice form provided for such purpose; and

(iii) Mark and identify the regulated article in accordance with § 340.5 of this part.

(g) *Withdrawal or denial of a permit.* Any permit which has been issued may be withdrawn by an inspector or the Deputy Administrator if he/she determines that the holder thereof has not complied with one or more of the conditions listed on the permit. APHIS will confirm the reasons for the withdrawal of the permit in writing within ten (10) days. Any person whose permit has been withdrawn or any person who has been denied a permit may appeal the decision in writing to the Deputy Administrator within ten (10) days after receiving the written notification of the withdrawal or denial. The appeal shall state all of the facts and reasons upon which the person relies to show that the permit was wrongfully withdrawn or denied. The Deputy Administrator shall grant or

[1] Renewals may receive shorter review. In the case of a renewal for a limited permit for importation that has been issued less than one year earlier, APHIS will notify the responsible person within 15 days that either: (1) The renewal permit is approved or (2) that a 90 day review period is necessary because the conditions of the original permit have changed.

deny the appeal, in writing, stating the reasons for the decision as promptly as circumstances allow. If there is a conflict as to any material fact, a hearing shall be held to resolve such conflict. Rules of practice concerning such a hearing will be adopted by the Administrator.

(h) *Courtesy permit—(1) Issuance.* The Deputy Administrator may issue a courtesy permit for the introduction of organisms modified through genetic engineering which are not subject to regulation under this part to facilitate movement when the movement might otherwise be impeded because of the similarity of the organism to other organisms regulated under this part.

(2) *Application.* A person seeking a courtesy permit shall submit on an application form obtained from Plant Protection and Quarantine data required by §§ 340.3(b)(1), (2), and (5) of this part and shall indicate such data is being submitted as a request for a courtesy permit. A person should also include a statement explaining why he or she believes the organism or product does not come within the definition of a regulated article. The application shall be submitted at least 60 days prior to the time the courtesy permit is sought.

(3) *Administrative action.* Plant Protection and Quarantine shall complete an initial review within 15 days of the date of receipt of the application. If the application is complete, the responsible individual shall be notified of the date of receipt of the application for purposes of advising the applicant when the 60 day review period commenced. If the application is not complete, the responsible individual will be advised what additional information must be submitted, and shall commence the 60 day review period upon receipt of the additional information, assuming the additional information submitted is adequate. Within 60 days from the date of receipt of a complete application, Plant Protection and Quarantine will either issue a courtesy permit or advise the responsible individual that a permit is required under § 340.3(b) or (c).

§ 340.4 Petition to amend the list of organisms.

(a) *General.* Any person may submit to the Deputy Administrator a petition to amend the list of organisms in § 340.2 of this part by adding or deleting any genus, species, or subspecies. A petitioner may supplement, amend, or withdraw a petition in writing without prior approval of the Deputy Administrator and without prejudice to resubmission at any time until the Deputy Administrator rules on the petition. A petition to amend the list of organisms shall be submitted in accordance with the procedures and format specified by this section.

(b) *Submission procedures and format.* A person shall submit two copies of a petition to the Deputy Administrator of Plant Protection and Quarantine, in care of the Director of the Biotechnology and Environmental Coordination Staff, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, 6505 Belcrest Road, Room 406, Federal Building, Hyattsville, Maryland 20782. The petition should be dated, and structured as follows:

Petition To Amend 7 CFR 340.2

The undersigned submits this petition under 7 CFR 340.4 to request the Deputy Administrator of Plant Protection and Quarantine, to [add the following genus, species, or subspecies to the list of organisms in 7 CFR 340.2] or [to remove the following genus, species, or subspecies from the list of organisms in § 340.2].

A. Statement of Grounds

[A person must present a full statement explaining the factual grounds why the genus, species, or subspecies to be added to § 340.2 of this part is a plant pest or why there is reason to believe the genus, species, or subspecies is a plant pest or why the genus, species, or subspecies sought to be removed is not a plant pest or why there is reason to believe the genus, species, or subspecies is not a plant pest. The petition should include copies of scientific literature which the petitioner is relying upon, copies of unpublished studies, or data from tests performed. *The petition should not include trade secret or confidential business information.*

A person should also include representative information known to the petitioner which would be unfavorable to a petition for listing or delisting. [If a person is not aware of any unfavorable information the petition should state, Unfavorable information: NONE].

B. Certification

The undersigned certifies, that to the best knowledge and belief of the undersigned, this petition includes all information and views on which the petitioner relies, and that it includes representative data and information known to the petitioner which are unfavorable to the petition.

(Signature) _____
(Name of petitioner) _____
(Mailing address) _____
(Telephone number) _____

(c) *Administrative action on a petition.* (1) A petition to amend the list of organisms which meets the requirements of paragraph (b) of this section will be filed by the Director of the Biotechnology and Environmental Coordination Staff, stamped with the date of filing, and assigned a docket number. The docket number shall identify the file established for all submissions relating to the petition. The Biotechnology and Environmental Coordination Staff, will promptly notify the petitioner in writing of the filing and docket number of a petition. If a petition does not meet the requirements of paragraph (b) of this section, the petitioner shall be sent a notice indicating how the petition is deficient.

(2) After the filing of a petition to amend the list or organisms USDA shall publish a proposal in the **Federal Register** to amend § 340.2 and solicit comments thereon from the public. An interested person may submit written comments to the Director of the Biotechnology and Environmental Coordination Staff on a filed petition, which shall become part of the docket file.

(3) The Deputy Administrator shall furnish a response to each petitioner within 180 days of receipt of the petition. The response will either: (i) Approve the petition in whole or in part in which case the Deputy Administrator shall concurrently take appropriate action (publication of a document in the **Federal Register** amending § 340.2 of this part; or (ii) deny the petition in whole or in part. The petitioner shall be notified in writing of the Deputy Administrator's decision. The decision shall be placed in the public docket file in the offices of the Biotechnology and Environmental Coordination Staff, and in the form of a notice published in the **Federal Register.**

§ 340.5 Marking and identity.

(a) Any regulated article to be imported other than by mail, shall, at the time of importation into the United States, plainly and correctly bear on the outer container the following information:

(1) General nature and quantity of the contents;

(2) Country and locality where collected, developed, manufactured, reared, cultivated or cultured;

(3) Name and address of shipper, owner, or person shipping or forwarding the organism;

(4) Name, address, and telephone number of consignee;

(5) Identifying shipper's mark and number; and

(6) Number of written permit authorizing the importation.

(b) Any regulated article imported by mail, shall be plainly and correctly addressed and mailed to Plant Protection Quarantine at a port of entry designated by an asterisk in 7 CFR 319.37-14(b) and shall be accompanied

by a separate sheet of paper within the package plainly and correctly bearing the name, address, and telephone number of the intended recipient, and shall plainly and correctly bear on the outer container the following information:

(1) General nature and quantity of the contents;

(2) Country and locality where collected, developed, manufactured, reared, cultivated, or cured;

(3) Name and address of shipper, owner, or person shipping or forwarding the regulated article; and

(4) Number of permit authorizing the importation;

(c) Any regulated article imported into the United States by mail or otherwise shall, at the time of importation or offer for importation into the United States, be accompanied by an invoice or packing list indicating the contents of the shipment.

§ 340.6 Container requirements for the movement of regulated articles.

(a) *General requirements.* A regulated article shall not be moved unless it complies with the provisions of paragraph (b) of this section, unless a variance has been granted in accordance with the provisions of paragraph (c) of this section. [8]

(b) *Container requirements*—(1) *Plants and plant parts.* All plants or plant parts, except seeds, cells, and subcellular elements, shall be packed in a sealed plastic bag of at least 5 mil thickness, inside a sturdy, sealed, leak-proof, outer shipping container constructed of corrugated fiberboard, corrogated cardboard, wood, or other material of equivalent strength.

(2) *Seeds.* All seeds shall be transported in a sealed plastic bag of at least 5 mil thickness, inside a sealed metal container, which shall be placed inside a second sealed metal container. Shock absorbing cushioning material shall be placed between the inner and outer metal containers. Each metal container shall be independently capable of protecting the seeds and preventing spillage or escape. Each set of metal containers shall then be enclosed in a sturdy outer shipping container constructed of corrugated fiberboard, corrugated cardboard, wood, or other material of equivalent strength.

(3) *Live microorganisms and/or etiologic agents, cells, or subcellular elements.* All regulated articles which are live (non-inactivated) microorganisms, or etiologic agents, cells, or subcellular elements shall be packed as specified below:

(i) *Volume not exceeding 50 ml.* Regulated articles not exceeding 50 ml shall be placed in a securely closed, watertight container (primary container, test tube, vial, etc.) which shall be enclosed in a second, durable watertight container (secondary container). Several primary containers may be enclosed in a single secondary container, if the total volume of all the primary containers so enclosed does not exceed 50 ml. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient nonparticulate absorbent material (e.g., paper towel) to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, corrugated cardboard, wood, or other material of equivalent strength.

(ii) *Volume greater than 50 ml.* Regulated articles which exceed a volume of 50 ml, shall comply with requirements specified in paragraph (b)(3)(i) of this section. In addition, a shock absorbing material, in volume at least equal to that of the absorbent material between the primary and secondary containers, shall be placed at the top, bottom, and sides between the secondary container and the outer shipping container. single primary containers shall not contain more than 1,000 ml. of material. However, two or more primary containers whose combined volumes do not exceed 1,000 ml. may be placed in a single, secondary container. The maximum amount of microorganisms or etiologic agents, cells, or subcellular elements which may be enclosed within a single outer shipping container shall not exceed 4,000 ml.

(iii) *Dry ice.* If dry ice is used as a refrigerant, it shall be placed outside the secondary container(s). If dry ice is used between the secondary container and the outer shipping container, the shock absorbing material shall be placed so that the secondary container does not become loose inside the outer shipping container as the dry ice sublimates.

(4) *Insects, mites, and related organisms.* Insects, mites, and other small arthropods shall be packed for shipment as specified in this paragraph or in paragraph (b)(3) of this section. Insects (any life stage) shall be placed in an escape-proof primary shipping container (insulated vacuum container, glass, metal, plastic, etc.) and sealed to prevent escape. Such primary container shall be placed securely within a secondary shipping container of crushproof styrofoam or other material of equivalent strength; one or more rigid ice packs may also be placed within the secondary shipping container; and sufficient packing material shall be added around the primary container to prevent movement of the primary shipping container. The secondary (styrofoam or other) container shall be placed securely within an outer shipping container constructed of corrugated fiberboard, corrugated cardboard, wood, or other material of equivalent strength.

(5) *Other macroscopic organisms.* Other macroscopic organisms not covered in paragraphs (b) (1), (2), and (4) of this section which do not require continuous access to atmospheric oxygen shall be packaged as specified in paragraph (b) (3) or (4) of this section. All macroscopic organisms which are not plants and which require continuous access to atmospheric oxygen shall be placed in primary shipping containers constructed of a sturdy, crush-proof frame of wood, metal, or equivalent strength material, surrounded by escape-proof mesh or netting of a strength and mesh size sufficient to prevent the escape of the smallest organism in the shipment, with edges and seams of the mesh or netting sealed to prevent escape or organisms. Each primary shipping container shall be securely placed within a larger secondary shipping container constructed of wood, metal, or equivalent strength material. The primary and secondary shipping containers shall then be placed securely within an outer shipping container constructed of corrugated fiberboard, corrugated cardboard, wood, or other material of equivalent strength, which outer container may have air holes or spaces in the sides and/or ends of the container, provided that the outer shipping container must retain sufficient strength to prevent crushing of the primary and secondary shipping containers.

(c) *Request for a variance from container requirements.* A responsible person who believes the container requirements normally applicable to the movement of the person's regulated article(s) are inappropriate due to unique circumstances (such as the nature, volume, or life stage of the regulated article) may submit in an application for a permit, a request for a variance from the container requirements. The request for a variance under this section shall consist of a short statement describing why the

[8] The requirements of this section are in addition to and not in lieu of any other packing requirements such as those for the transportation of etiologic agents prescribed by the Department of Transportation in Title 49 of the Code of Federal Regulations or any other agency of the Federal government.

normally applicable container requirements are inappropriate for the regulated article which the person proposes to move and what container requirements the person would use in lieu of the normally prescribed container requirements. USDA shall advise the responsible person in writing at the time a permit is granted on the person's request for a variance.

§ 340.7 Cost and charges.

The services of the inspector during regularly assigned hours of duty and at the usual places of duty shall be furnished without cost.[9] The U.S. Department of Agriculture will not be responsible for any costs or charges incident to inspections or compliance with the provisions of this part, other than for the services of the inspector.

[9] The Department's provisions relating to overtime charges for an inspector's services are set forth in 7 CFR Part 354.

Done at Washington, DC, this 10th day of June, 1987.

D. Husnik,

Acting Deputy Administrator, Plant Protection and Quarantine, Animal and Plant Health Inspection Service.

[FR Doc. 87-13589 Filed 6-15-87; 8:45 am]

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Forage Genetics International
N5292 Gills Coulee Road
West Salem, WI 54669
(608) 786-2121

August 6, 2010

Mr. Michael C. Gregoire
Deputy Administrator
Biotechnology Regulatory Services
Animal and Plant Health Inspection Service
U.S. Department of Agriculture
4700 River Road, Unit 98
Riverdale, MD 20737

Re: Environmental Report - Partial Deregulation Measures for Cultivation of Roundup Ready® Alfalfa Events J101/J163

Dear Mr. Gregoire:

Forage Genetics International, LLC ("FGI"), a wholly owned subsidiary of Land O'Lakes, Inc. ("Land O'Lakes"), is an alfalfa breeding and seed production company and one of the original petitioners who sought a determination of non-regulated status for glyphosate-tolerant alfalfa in Docket No. APHIS-2007-0044. On behalf of the cooperative members of Land O'Lakes and our customers, we are writing to request that the Animal and Plant Health Inspection Service ("APHIS") grant a temporary "partial deregulation" or implement other administrative interim measures to mitigate the harm to the interests of those members and farmers resulting from delays in commercial planting of glyphosate-tolerant alfalfa. We request that such measures be implemented until such time as APHIS concludes its review of the petition for non-regulated status and its new decision on the petition takes effect. The proposed interim measures are consistent with the type of partial deregulation discussed recently by the U.S. Supreme Court in the *Geertson* case.

Land O'Lakes

Land O'Lakes is a farmer-owned food and agricultural cooperative representing the interests and needs of more than 300,000 direct and indirect members across America.

Land O'Lakes was organized in 1921 with the goals of enabling a stronger presence in the marketplace and of giving farmer-members a stronger voice in their own economic destinies. As a farmer-owned cooperative, Land O'Lakes proved to be an idea, and an organization, that worked for its producer-members. In the late 1920s, members asked us

to take that cooperative idea into the agricultural inputs marketplace, and we entered the farm supply business. Our goal at that time was to provide farmer-members a secure, competitively priced supply of high-quality inputs. It was from those beginnings that our current Feed, Seed and Crop Protection Products businesses were born. Innovation is a hallmark of Land O'Lakes' performance in both agricultural inputs and the food side of our business.

Our structure as a cooperative continues to benefit members in a variety of ways: generating market access (and capturing value from the market) for our farmer-members; providing a secure source of high-quality agricultural inputs; enabling members to participate in the profits/losses generated by our businesses; and developing and delivering new products and services tailored to member needs. And, through their representation on our board of directors, our farmer-members exercise control over the strategic direction of the cooperative. Ultimately, a key element in determining that strategic direction is our stated Mission of "optimizing the value of our members' dairy, crop and livestock production."

A Leader in Agricultural Technology

FGI is a vertically integrated alfalfa seed company involved in basic R&D, plant breeding/product development, seed production, sales and marketing of alfalfa seed. Our research efforts include the development of biotechnology traits and conventional breeding. The seed products we develop are sold in both the U.S. and export markets, and to both conventional and organic alfalfa producers.

We see significant grower value for biotechnology traits, but understand that there are sectors of the U.S. and global markets that will choose not to plant alfalfa with these traits. The continued success of our business depends on our ability to serve all of these markets – biotechnology, conventional and organic – and includes a commitment to stewardship practices that enable market and environmental coexistence. Again, this dedication to sound science and producer choice is an important part of our company culture.

Biotechnology can play a significant role in the future of alfalfa, which is the fourth largest crop grown in the U.S. and is a key component of the diet of dairy cows. Alfalfa acres have been declining over the past 20 years, due in part to weed and quality issues. Additionally, growers have reduced the amount of alfalfa planted in part because the availability of biotechnology in other crops provides growers a better opportunity to manage production risks compared to growing conventional alfalfa. As acres of alfalfa decline, so too do the benefits that alfalfa provides as a key contributor to sustainable agriculture, including:

- Nitrogen fixation/crop rotation benefits
- Reduced soil erosion compared with row crops
- Deep, extensive root systems that improve soil tilth and sequester carbon

- Key source of digestible fiber and protein that can be produced right on the farm for the diet of dairy cows.

In order to address the problems in alfalfa caused by weed and quality issues, FGI has worked with Monsanto Company ("Monsanto") to develop glyphosate-tolerant alfalfa known as Roundup Ready® alfalfa ("RRA"). Under an exclusive license from Monsanto, FGI has been the developer, a seed producer, and seller of RRA. FGI's alfalfa breeding program developed all of the initial RRA cultivars and, along with one other seed company licensed by FGI, has contracted the production of all of the RRA seed sold prior to March 2007. All seed harvested thereafter was placed in controlled storage subject to Court Order and APHIS Administrative Rule. Though it is FGI's intent to license other alfalfa breeding companies to develop RRA varieties in the future, FGI is currently the sole source of seed available for RRA varieties for planting. The RRA seed is to be sold by seed companies that are licensed by Monsanto to sell the product to licensed forage growers.

History of RRA

RRA was deregulated in June 2005 by APHIS following preparation of an Environmental Assessment (which included public comment) and the issuance of a Finding of No Significant Impact – a process consistent with 78 prior or more recent deregulation decisions issued by the agency.

In February of 2007, Judge Charles Breyer of the United States District Court for the Northern District of California held that APHIS had not taken a sufficiently "hard look" in its Environmental Assessment of RRA at certain specific issues in support of the agency's decision to deregulate RRA. Judge Breyer's determination focused principally on the potential for gene flow from RRA to conventional or organic alfalfa seed fields, noting that alfalfa seed production has traditionally occurred in certain fairly concentrated areas of certain Western states. Although Judge Breyer also expressed concern regarding a possibility of flowering by alfalfa forage crops, APHIS' experts, along with multiple academic experts, concluded that the possibility for gene flow from one forage field to another was highly remote. The evidence submitted in the case also indicated that RRA growers would suffer significant harm in excess of $200 million from a halt in their ability to plant and use RRA for forage production for crop years 2007, 2008 and spring 2009.

Judge Breyer issued a preliminary injunction in March 2007 preventing any new planting of RRA beginning March 30, 2007, and subsequently issued a permanent injunction in May 2007 that enjoined further planting and sale of RRA pending completion of an Environmental Impact Statement ("EIS"). The injunction allowed the continued harvest of hay and seed production fields established prior to March 30, 2007, subject to certain conditions imposed by the court. Finally, the court enjoined APHIS from granting the RRA deregulation petition "even in part" before preparation of an EIS.

® Roundup Ready is a registered trademark of Monsanto Technology LLC.

During the remedy phase in Judge Breyer's court, APHIS representatives testified that they believed the agency would conduct an EIS within two years of the court order. Based largely on APHIS' estimated timeline, FGI elected to honor its seed production contracts with individual seed growers rather than pay to terminate these contracts. FGI purchased seed from the seed growers of RRA varieties produced in 2007, 2008 and 2009. All RRA seed purchased by FGI during these years was produced under multi-year grower contracts in place prior to the injunction. FGI also recalled from its seed company customers, who in turn recalled from their customer-growers, RRA seed produced and shipped but not planted prior to March 30, 2007. Thus, millions of pounds of RRA seed are in controlled storage.

Preparation of the EIS has taken APHIS longer than anticipated. Next spring will mark the fourth anniversary of the injunction and the EIS has not been completed.

Impacts of *Geertson* Litigation – The Risk of Further Delay

Although all RRA seed is now in storage conditions designed to optimize medium-term seed viability, seed quality is beginning to deteriorate. Based on our tracking of changes in germination percentages over the last 12 months, and our experience with typical patterns in seed quality decline, we believe that missing the spring 2011 commercial planting opportunity would place a significant volume of seed stocks at risk of deteriorating below current Certified Seed quality standards.

Any further delay in commercial planting opportunity would greatly increase potential losses. The RRA inventory described above, and the risk associated with this inventory, is owned by FGI, and passed on to our parent company and, ultimately, its farmer-members.

Prior to Judge Breyer's injunction, approximately 5,500 growers planted about 250,000 acres of RRA in the fall 2005, spring 2006, fall 2006, and/or truncated spring 2007 planting seasons. In a survey of a random sampling of these 5,500 RRA growers, farmers self-report a yield advantage of 0.9 tons/per acre/per year for RRA, when compared to conventional hay production on their farms. Based on average current hay prices, that translates into a $110 per acre/per year farm-gate advantage. Based on expected potential sales in the spring of 2011, typical planting rates and an average four-year rotation, the aggregated incremental value of RRA associated with spring 2011 planting alone is approximately $160 million.

A missed opportunity to plant RRA in spring 2011 is lost income for alfalfa growers, particularly important during the recent period of lower hay prices and a difficult dairy economy.

Request for Temporary Partial Deregulation or Other Interim Measures

The District Court's injunction on planting of RRA was ultimately appealed to the U.S. Supreme Court. In its decision of June 21, 2010, the Court overturned Judge Breyer's

injunction and specifically anticipated the ability of APHIS to take interim measures by partially deregulating RRA with appropriate mitigation conditions during the continued preparation of the EIS. In the Supreme Court's own words, "a partial deregulation need not cause respondents any injury at all, much less irreparable injury; if the scope of the partial deregulation is sufficiently limited, the risk of gene flow to their crops could be virtually nonexistent." The Supreme Court remanded the *Geertson* case for further proceedings consistent with its June 21 opinion.

In the interest of our farmer member/owners and alfalfa growers in general, we are requesting that APHIS grant such an interim partial deregulation of RRA. Our co-petitioner, Monsanto, concurs in this request. Enclosed for your reference is an Environmental Report which discusses a set of proposed interim measures, consistent with the measures discussed recently by the Supreme Court, along with the potential environmental impact of those measures. We set forth these proposed measures and conditions of use in the context of the ongoing RRA litigation. Although there has been no evidence of any actual harm to the environment from multiple years of RRA seed and forage crop cultivation to date, these measures are nevertheless crafted to further minimize (if not eliminate) any perceived risks previously identified in the litigation context. In short:

- For RRA seed production, only eight pre-authorized seed grower consortia at physically isolated locations would be allowed during this interim period. The seed growers at these specific pre-authorized locations have requested the opportunity to produce RRA seed and would be required to follow the best management practices of the National Alfalfa and Forage Alliance ("NAFA"). These best practices have been adopted by the industry as standards for any future RRA seed production as part of an overall stewardship program designed to ensure coexistence of various alfalfa hay and seed markets. In addition, certain minimum isolation requirements for RRA seed fields would be increased during this interim period.

- For production of RRA forage (i.e., hay or haylage), our request includes a number of interim measures, including seed identification requirements, field tracking and geographic restrictions that would locate the very large majority of these RRA forage production acres in areas with no alfalfa seed production at all. It is important to note that over 99% of the alfalfa planted in the United States is planted for harvest as forage.

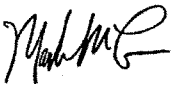
Conclusion

In sum, we propose that APHIS grant our request for limited interim measures designed to mitigate harm to thousands of growers until APHIS' final decision on the petition for non-regulated status takes effect. By granting our request for partial deregulation of RRA, APHIS would protect the interests of agriculture and consumers and, at the same time, address potential environmental impacts cognizable under the National

Environmental Policy Act by providing for a negligible risk of gene flow from RRA plantings.

FGI, Land O'Lakes and our farmer member/owners appreciate the efforts APHIS has made to address the challenges that have been raised to the commercialization of RRA and pledge our continued support and cooperation as we face the challenges that lie ahead. Your prompt consideration of this request for interim administrative action will be greatly appreciated. Please contact me with any questions concerning this request.

Sincerely,



Mark McCaslin, PhD
President

Enclosure

cc: Monsanto Company

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By APHIS BRS Document Control Officer at 3:12 pm, Aug 06, 2010

ENVIRONMENTAL REPORT
Partial Deregulation Measures for Cultivation of Roundup Ready® Alfalfa Events J101/J163

August 5, 2010

ACRONYMS AND ABBREVIATIONS

ACCase	acetyl-CoA carboxylase (enzyme)
ADF	Acid detergent fiber
ai/A	Active ingredient per acre
ALS	acetolactate synthase (enzyme)
AMS	Agricultural Marketing Service (USDA)
AOSCA	Association of Official Seed Certifying Agencies
AP	Adventitious presence
APHIS	Animal and Plant Health Inspection Service (USDA)
ASTA	American Seed Trade Association
BMP	Best Management Practices
BNF	Biotechnology Notification Files
BRS	Biotechnology Regulatory Service (USDA APHIS)
BST	Bovine somatotropin
CEQ	Council on Environmental Quality
CFIA	Canadian Food Inspection Agency
C.F.R.	Code of Federal Regulations
CRLF	California red-legged frog
CTIC	Conservation Technology Information Center
CTP2	Chloroplast transit peptide
d	Dose
DNA	Deoxyribonucleic Acid
EA	Environmental Assessment
EC	European Commission (EU)
EEC	Estimated Environmental Concentration
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency (U.S.)

EPSPS	5-enolpyruvylshikimate-3-phosphate synthase (enzyme)
ER	Environmental Report
ERS	Economic Research Service (USDA)
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FDA	Food and Drug Administration (U.S.)
FFDCA	Federal Food, Drug, and Cosmetic Act
FGI	Forage Genetics International
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FONSI	Finding of No Significant Impact
FQPA	Food Quality Protection Act
FSANZ	Food Standards Australia New Zealand
ft	feet
GE	Genetic engineering or genetically engineered
GM	Genetically modified
GMO	Genetically modified organism
GPS	Global Positioning System
GR	Glyphosate resistant
GT	Glyphosate-tolerant
HSP70	Heat shock protein intron
IM/NRC	Institute of Medicine and National Research Council
in.	Inches
IPA	Isopropylamine salt
lbs.	Pounds
IM	Institute of Medicine
kg	Kilograms

M	Mendelian manner
mg	Milligrams
MRID	Master Record Identification Number
MT/SA	Monsanto Technology Stewardship Agreement
NA	National Academies
NAFA	National Alfalfa and Forage Alliance
NAS	National Academy of Science
NASS	National Agricultural Statistical Service (USDA)
NCBA	National Cattlemen's Beef Association
NDF	Neutral detergent fiber
NEPA	National Environmental Policy Act
No.	Number
NOP	National Organic Program
NRC	National Research Council
OECD	Organization for Economic Cooperation and Development
OFPA	Organic Foods Production Act
OSTP	Office of Science and Technology Policy
PNT	Plant with a Novel Trait
PNW	Pacific Northwest
POEA	Polyethoxylated Tallow Amine
PPA	Plant Protection Act
ppm	Parts per million
rDNA	Recombinant DNA
RED	Reregistration Eligibility Decision
RfD	Reference Dose
ROD	Record of Decision

RR	Roundup Ready
RRA	Roundup Ready® Alfalfa
TUG	Technology use guide
T-DNA	Transferred DNA
UC	University of California
µg	Micrograms
U.S.	United States
U.S.C	U.S. Code
USDA	U.S. Department of Agriculture
USDC	U.S. District Court
WHO	World Health Organization
WSSA	Weed Science Society of America
wt	weight

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Appendix A Monsanto Technology Stewardship Agreement (MT/SA) and accompanying Technology Use Guide (TUG)

Appendix B National and Tier III Production Data and State Maps with County-level Detail for the Eleven Tier III States with Seed Production greater than 100,000 lbs.

Appendix C National Alfalfa & Forage Alliance Best Management Practices for Roundup Ready® Alfalfa Seed Production.

Appendix D Orloff, S., D.H. Putnam, M. Canevari and W.T. Lanini, Avoiding Weed Shifts and Weed Resistance in Roundup Ready Alfalfa Systems, University of California Division of Agriculture and Natural Resources Publication 8362 (2009).

Appendix E Effects of Glyphosate-Resistant Weeds in Agricultural Systems (Appendix G from Draft EIS).

Appendix F Selected Comments to Draft Environmental Impact Statement from Farmers Using Roundup Ready Alfalfa.

Appendix G Chart of Anticipated Adoption of RRA under Partial Deregulation, Prepared by Monsanto/FGI (August 4, 2010).

Appendix H Roundup Ready Alfalfa Satisfaction Study (Study #091 113 1108) Prepared by Market Probe, Inc. (December 2008).

Appendix I Putnam, D. and D. Undersander. 2009. Understanding Roundup Ready Alfalfa (full version). Originally posted on the Hay and Forage Grower Magazine web site at: http://hayandforage.com/understanding_roundup_ready_alfalfa_revised.pdf (January 1, 2009).

Appendix J Roundup Ready Alfalfa Harvesting Study, Study # 3482 (originally submitted as Appendix 6 to Monsanto/FGI comment to draft EIS).

Appendix K Fitzpatrick, S. and G. Lowry. 2010. Alfalfa Seed Industry Innovations Enabling Coexistence. Proceedings of the 42nd North American Alfalfa Improvement Conference, Boise, Idaho, July 28-30, 2010.

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SECTION 1.0 INTRODUCTION

This Environmental Report (ER) examines the environmental impacts of cultivation of Roundup Ready® alfalfa (RRA) lines J101 and J163 (J101/J163)[1] for a temporary period subject to a range of measures, including geographic restrictions, stewardship requirements and other limitations. This ER is provided in connection with the petitioners' supplemental request for non-regulated status *in part* (commonly known as "partial deregulation") for RRA. This document is intended to provide information that may be utilized by the United States Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) in complying with the National Environmental Policy Act (NEPA)[2] and its applicable regulations[3] either in connection with partial deregulation of RRA or for any other regulatory or administrative action adopting the measures addressed herein. A partial deregulation or other administrative action adopting the measures may be superseded at a later date after APHIS completes the Environmental Impact Statement (EIS) and makes its determination regarding the pending petition for complete deregulation of RRA.

Alfalfa (*Medicago sativa* L.) was planted on approximately 21 million acres in the U.S. in 2009. Overall crop value was $7.9 billion in the 2009-2010 crop year. Over 99 percent of the alfalfa planted in the U.S. is planted for harvest as forage, with less than one percent harvested for seed. RRA, which has been genetically engineered to be tolerant to the herbicide glyphosate, is currently cultivated on approximately 200,000 acres or less, (USDA NASS, 2010b; USDA APHIS, 2009), pursuant to permit or court order.

1.1 PURPOSE OF THIS ER

1.1.1 Background

In April 2004, under the requirements of the Plant Protection Act (PPA)[4] and its implementing regulations,[5] Monsanto Company (Monsanto) and Forage Genetics International (FGI) submitted a petition to APHIS for a determination of non-regulated status for RRA (Rogan and Fitzpatrick, 2004). Monsanto is an agricultural company involved in the development and marketing of biotechnology-derived agricultural products. FGI is an alfalfa seed company and a

[1] The terms RRA and glyphosate tolerant alfalfa,or GT alfalfa are used interchangeably throughout this document.
[2] NEPA of 1969, as amended; Title 42 of the U.S. Code (42 U.S.C.) §§4321-4347.
[3] Council on Environmental Quality (CEQ) regulations implement NEPA and are found in Title 40 of the Code of Federal Regulations (40 C.F.R.), Parts 1500 through 1508. The U.S. Department of Agriculture has implemented NEPA regulations, which are found at 7 C.F.R. part 1b, as has APHIS, and those are found at 7 C.F.R. part 372.
[4] 7 U.S.C. §§7701-7786.
[5] 7 C.F.R. Part 340.

wholly-owned subsidiary of Land O'Lakes, Inc., a farmer-owned food and agricultural cooperative representing the interests and needs of more than 300,000 direct and indirect members across the U.S. APHIS, through its Biotechnology Regulatory Service (BRS), is one of three federal agencies responsible for regulating biotechnology in the U.S. under the Coordinated Framework described in Section 1.4. APHIS regulates genetically engineered (GE) organisms that may be plant pests, the Environmental Protection Agency (EPA) regulates plant incorporated protectants and herbicides used with herbicide-tolerant crops, and the U.S. Department of Health and Human Services' Food and Drug Administration (FDA) regulates food and animal feed. The FDA completed its consultation process for RRA in 2004 (Tarantino, 2004). EPA approved the use of glyphosate over the top of RRA on June 15, 2005. The use of glyphosate over the top of RRA did not require an increase in the existing glyphosate residue tolerance of 400 ppm in the animal feed, non-grass crop group. EPA issued a new glyphosate tolerance for alfalfa seed of 0.5 ppm on February 16, 2005.[6]

NEPA requires federal agencies to evaluate the potential impact of proposed major federal actions and consider such impacts during the decision-making process. After agency review for safety, including an evaluation of relevant scientific data and all public comments relating to potential plant pest risks and related environmental impacts, APHIS issued an Environmental Assessment (EA) pursuant to NEPA in 2005 (USDA APHIS, 2005). Based on that EA, APHIS reached a finding of no significant impact (FONSI) on the environment from the unconfined cultivation and agricultural use of RRA and its progeny (USDA APHIS, 2005). Accordingly, in June 2005, APHIS granted non-regulated status to RRA (USDA APHIS, 2005).

After RRA was deregulated, the seeds were sold and planted. During the growing season of 2005 and 2006, approximately 200,000 acres were planted in 1,552 counties in 48 states (Alaska and Hawaii were not included). Approximately nine months after APHIS granted non-regulated status to RRA, two alfalfa seed growers and seven associations filed a lawsuit against the USDA over its decision to deregulate RRA, claiming that APHIS' EA failed to adequately consider certain environmental and economic impacts as required by NEPA. In February 2007, the court granted the plaintiffs' motion for summary judgment, finding that APHIS is required to prepare an EIS before approving its deregulation of RRA, and vacated APHIS' 2005 decision to deregulate RRA (U.S. District Court (USDC), 2007a). On March 12, 2007, the Court issued a preliminary injunction order in the case (USDC, 2007b). The order prohibited all sales of RRA seeds, effective on the date of the order, pending the Court's issuance of permanent injunctive

[6] 40 C.F.R. §180.364; 70 Fed. Reg. 7864 (Feb. 16, 2005).

relief; and prohibited all future planting, beginning March 30, 2007. The Court also vacated APHIS's deregulation determination. On March 23, 2007, APHIS published a notice in the Federal Register describing the Court's decision that RRA was once again a regulated article.[7] On May 3, 2007, the Court issued a permanent injunction regarding the control of the RRA that had been planted, and requiring APHIS to issue an administrative order specifying mandatory production practices that must be implemented by RRA growers (USDC, 2007c). The Court issued an amended judgment on July 23, 2007, further clarifying the mandatory production practices (USDC, 2007d). APHIS issued its administrative order on July 12, 2007 (USDA APHIS, 2007a). In August and September 2007, USDA, Monsanto, FGI and others filed an appeal, arguing that the injunction was improper. After the Ninth Circuit Court of Appeals affirmed the district court decision, the U.S. Supreme Court decided to hear the case. In June 2010, in *Monsanto Co. et al. v. Geerston Seed Farms et al.*, the Supreme Court overturned the lower court ruling, striking down the injunction.

Following issuance of the district court's amended judgment in July 2007, APHIS commenced work on the EIS for complete deregulation. The Notice of Intent was published in the Federal Register on January 7, 2008.[8] The notice of availability for the draft EIS was published in the Federal Register on December 18, 2009.[9] In the draft EIS, APHIS preliminarily concluded that there is no significant impact on the human environment due to granting nonregulated status to RRA (USDA APHIS, 2009). The comment period for the draft EIS, following an extension granted by APHIS, concluded on March 3, 2010. Approximately, 145,000 comments were submitted. APHIS is now preparing the final EIS.

1.1.2 Purpose of and need for action

This ER has been prepared to support an anticipated EA to be prepared by APHIS with respect to a partial deregulation of RRA. The ER examines the environmental impacts of implementing the proposed measures laid out below, either through a partial deregulation of RRA or other administrative means. The proposed measures would allow commercialization and deregulation of RRA in limited areas and under specific cultivation conditions explained more fully below in Section 1.1.3. If APHIS concludes that an EA supports a FONSI for the proposed measures, APHIS could decide to implement such measures through "partial deregulation".

[7] 72 Fed. Reg. 13735 (Mar. 23, 2007).
[8] 73 Fed. Reg. 1198 (Jan. 7, 2008).
[9] 74 Fed. Reg. 67205 (Dec. 18, 2009).

1.1.3 The proposed measures

Monsanto/FGI have proposed the following measures to be implemented through partial deregulation or other administrative means. The companies state that these measures would allow a subset of alfalfa farmers to obtain the substantial benefits of RRA pending complete deregulation. For example, they expect RRA to (i) offer growers a wide-spectrum weed control option that will enhance stand establishment and increase alfalfa forage; (ii) increase flexibility to treat weeds on an as-needed basis; (iii) allow alfalfa production on marginal land with severe weed infestations; and (iv) provide growers with a weed control system that has a reduced risk profile for the environment. The proposed measures include a separate set of restrictions for RRA forage production and RRA seed production. These restrictions are described in the sections below.

FORAGE PRODUCTION RESTRICTIONS

1) **Grower Requirements**: Each grower is required to abide by the terms specified in their Monsanto Technology / Stewardship Use Agreement (MT/SA) and accompanying Technology Use Guide (TUG), which contractually obligates growers to comply with stewardship requirements related to growing RRA for forage. A copy of the MT/SA and TUG are included in Appendix A.
2) **RRA Seed Licensing Requirements**: All RRA seed is sold through a network of licensed seed companies and their retailers and dealers/distributors. Each seed company is required to have a current Genuity® Roundup Ready® Alfalfa Commercial License Agreement to sell RRA seed. This agreement specifies the limited rights of the seed companies to market the product, including stewardship requirements associated with RRA.
3) **Seed Identification**: RRA seed bag labeling and a unique purple seed colorant will be required product identity mechanisms to notify all RRA forage growers of the presence of the RRA trait and the geographic limitations for product use.[10]
4) **Crop Harvest (Forage only)**: RRA fields, except as noted under "Seed Production Restrictions" Section below, may be harvested for forage only. All growers shall adhere to limitations as outlined in the MT/SA and TUG (Monsanto TUG, attached as Appendix A).[11]

[10] Similar labeling and use agreements are typically used for the sale and stewardship of other GE crops, so growers are currently familiar with such contractual obligations.

[11] Forage growers who have previously used RRA are familiar with this crop use limitation. See Appendix A.

5) **Geographic Restrictions for Forage Planting based on Cropping Practices**:
Geographic restrictions will be placed on forage planting by state and county based on the amount of alfalfa seed produced (see Appendix B). Data on the amount of seed produced is from the 2007 Census of Agriculture, as summarized in Figure 1-1 (for additional details see Table 1-1 and Appendix B). Geographic restrictions for alfalfa forage plantings will be defined in three categories (Tiers I, II, and III) based on the amount of alfalfa seed production reported in each state. (See Appendix B for maps).

   a. Tier I: States with no reported alfalfa seed production (2007); 27 States and all counties within each.

      i. New RRA forage production plantings are allowed in accordance with the requirements established by the TUG and Genuity® Roundup Ready® Alfalfa Commercial License Agreement.

      ii. Forage growing is the only reported crop practice for alfalfa. No commercial alfalfa seed growth was reported in Tier I states in 2007. However, if conventional seed production fields are now present, then RRA forage grown near these new conventional seed production fields are subject to the requirement provided in Restriction Enhancement A (see Tier II.ii below).

   b. Tier II: States with <100,000 lbs annual seed production (2007); 12 States and all counties within each.
   Commercial alfalfa seed production occurs in these states; however, the number of seed growers, seed acres and cumulative pounds are limited and widely dispersed. Only 0.51 percent of the U.S. alfalfa seed crop is produced in these states (2007).

      i. New RRA forage production plantings are allowed in accordance with the requirements established by the TUG and Genuity® Roundup Ready® Alfalfa Commercial License Agreement.

      ii. Restriction Enhancement A applies if the RRA forage field is located within 165 ft of a commercial, conventional alfalfa seed production field. Under Restriction Enhancement A, the RRA grower must harvest forage before 10 percent bloom.

1. *Rationale for Restriction Enhancement A*: In grower locations where an individual RRA forage field is within 165 ft of a conventional seed production field, the TUG requires the RRA grower to mitigate RRA flowering by harvesting not later than 10 percent bloom stage to mitigate pollen production. RRA forage grower compliance with the TUG's 10 percent bloom stage harvest has been high and rarely was it delayed by weather or other factors. (See Appendix J). This restriction will address mitigations at or near geographic (county, state and federal) borders. The 165 ft distance is the science and market-based, industry recognized isolation distance for certified alfalfa seed crops (see Association of Official Seed Certifying Agencies (AOSCA), 2009); and, the potential extent of gene flow of 10 percent bloom hay to nearby seed crops is de minimis at 165 ft (Teuber and Fitzpatrick, 2007; Van Deynze et al., 2008).

c. Tier III: States each having >100,000 lbs annual seed production (2007); 11 States. Enhanced restrictions to be applied based on predominant county cropping practices. In the eleven states with greater than 100,000 acres of annual alfalfa seed production, additional by-county geographic restrictions will apply. In many cases, within each state, seed acreage is geographically concentrated and typically localized to a few specific counties where climate is suitable for seed growing. (See geographic maps for each of these states in Appendix B.) In these states, alfalfa seed is typically grown by professional growers under seed company contracts and official seed certification inspection programs are widely used by growers and the contracting seed companies. Alfalfa forage production is also a major enterprise in these states and in many cases it is geographically separate from seed crop acres.

    i. By-County criterion used to determine eligibility for new RRA forage plantings.

        1. Counties without seed production reported (Appendix B).

a. New RRA forage production is allowed in accordance with the requirements established by the TUG and Genuity® Roundup Ready® Alfalfa Commercial License Agreement.

b. Restriction Enhancement A: If RRA forage field is located within 165 ft of a conventional alfalfa seed field, RRA grower must harvest forage at or before 10 percent bloom.

c. Restriction Enhancement B: All RRA forage growers are required to report GPS coordinates of all RRA forage field locations. GPS field location information is available for monitoring and enforcing the planting restrictions applicable to RRA forage fields.

d. Forage production is the only reported crop practice in these counties. Commercial alfalfa seed growing is not reported.

2. Counties with seed production reported (Appendix B).

a. Restriction Enhancement C: New RRA forage plantings are not allowed in counties with commercial alfalfa seed production.

b. Commercial alfalfa seed growing is a predominant activity in these counties

c. 99.5 percent of U.S. alfalfa seed production is in these counties.

6) **Summary of Allowed Forage Production Scope:**

a. Nationwide, the counties excluded from new RRA forage production under the requested partial deregulation represent 99.5 percent and 21.84 percent of the alfalfa seed production pounds (lbs) and forage production acres, respectively (See Appendix B).

b. Nationwide, the counties where new RRA forage plantings are allowed (with various restrictions) include 0.5 percent and 78.16 percent of the alfalfa seed production (lbs) and forage production acres, respectively.

7) **Monitoring and Enforcement of Forage Crop Restrictions**

Support and enforcement of the partial deregulation of RRA for forage production would be accomplished by the following mechanisms.

a. **Education and Communication**: Education and communication activities would be conducted with hay growers, seed dealers/sellers and seed companies. Examples of these activities include training and information sessions for dealers and sellers, detailing the requirements for selling RRA, sales meetings, periodic visits with growers and sellers, and computer based training modules that can be tailored to specific areas of focus related to the product and requirements.

i. **Training**: Online training would be required for each seed company staff member handling RRA as well as the appropriate personnel at Monsanto/FGI.

ii. **The MT/SA and accompanying Monsanto TUG**: The MT/SA and accompanying TUG, a legal agreement between growers who utilize Monsanto technologies and Monsanto, would be updated to include direct reference to the partial deregulation conditions, including the limitations pertaining to where RRA forage can be grown and hay and forage management practices.

iii. **Packaging Updates**: In addition to being clearly labeled as RRA seed, all bags of finished product would have an additional prominent tag that lists the states and counties in which the product could not be planted. In addition the seed would have a unique coating color (purple) that identifies it as being RRA seed.

iv. **Dealer Requirements**: All dealers selling RRA would sign a dealer agreement legally binding them to adhere to the partial deregulation requirements.

v. **Industry Communications**: Alfalfa industry-specific groups would be utilized to support communication of the partial deregulation requirements in communications to their members. These include National Alfalfa and Forage Alliance (NAFA), American Seed Trade Association (ASTA), etc.

vi. **RRA Information Line**: A toll free number will be available for growers or other individuals to clarify information or answer questions regarding the partial deregulation.

b. **Assessment and Verification**: Multiple assessment and verification tools will be utilized to monitor and verify adherence to the partial deregulation request.

i. **Reconciliation of Sales Data**: All sales to hay growers will be reconciled with remaining RRA seed inventory at the end of the planting season (twice per year). This reconciliation will be part of a legal commercial requirement of the seed companies and dealers selling RRA.

ii. **GPS coordinates**: GPS coordinates will be collected on all sales in the eleven (11) Tier III states. The GPS coordinates will be collected on all fields planted with RRA. Information will be validated at time of receipt; questionable data will be reviewed.

iii. **Hotline**: A toll-free hotline will be available for individuals to report violations to the partial deregulation ruling.

c. **Proactive Sampling, Testing and Review, inclusion of third parties**: Various internal and/or third parties will be utilized to randomly review plantings and to determine grower compliance with the conditions of the partial deregulation.

d. **Enforcement**: Violations of the partial deregulation decision will have the following impacts:

i. **Grower**: Takeout of the alfalfa field in violation would be required. Grower has the potential to lose access to RRA.

ii. **Dealer**: Any dealer incentive payments would be at risk. In addition, dealers would also risk losing their ability to sell RRA in the future.

iii. **Seed Company**: Any seed company incentive payments would be at risk. In addition, seed companies would also risk losing their ability to sell RRA in the future.

e. **Ongoing Measurement**: An annual report would be prepared by FGI for the USDA summarizing activities in all areas identified above. Additional data would be provided upon request.

f. **Any potential additional investigation or action** would be conducted in accordance with all federal, state and local laws concerning individual property rights, inspections and sampling activities. Monsanto has demonstrated that it does not exercise its patent rights where trace amounts of patented seeds or traits are present in a farmer's fields as a result of inadvertent means.

Table 3-9. State Production of Alfalfa Seed (2007 Census of Agriculture).

State	Farms	Seed Acres Harvested	Pounds of Seed Harvested
California	114	36,625	19,083,458
Washington	82	17,127	10,860,608
Idaho	92	12,788	9,346,709
Wyoming	62	10,548	5,915,816
Nevada	19	6,498	4,237,101
Montana	80	10,338	3,729,635
Oregon	32	4,959	3,183,375
Utah	54	3,803	2,077,813
Arizona	53	5,206	1,902,669
South Dakota	47	6,014	428,447
Oklahoma	29	2,004	281,121
Texas	24	546	79,885
Minnesota	17	611	63,461
Missouri	19	399	40,540
North Dakota	6	(D)	34,784
New Mexico	15	310	29,907
Kansas	5	342	22,430
Nebraska	29	545	21,216
Michigan	10	(D)	15,610
New York	3	27	6,180
Iowa	5	(D)	(D)
Ohio	1	(D)	(D)
Colorado	8	1,815	(D)

(D): Data withheld to avoid disclosing data for individual farms.

Figure 1-1. Table 3-9 from Draft EIS for RRA.

Table 1-1 Alfalfa Seed and Hay Production Overview (State List)

	State	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds	Alfalfa Hay - Acres	Alfalfa Hay - Operations	Alfalfa Hay - Tons	Existing Seed Production Category	Restrictions on new RRA forage plantings (all counties within state)	Within State By-County Geographic Criteria and Restrictions on new RRA forage production
Tier I: States with no reported alfalfa seed production (2007)	ALABAMA				7,526	340	16,944	None	TUG restrictions, plus, if field is within 165 ft of conventional seed production, then <10% bloom cut required	Not Applicable
	ALASKA				-	-	-	None		
	ARKANSAS				11,732	278	28,647	None		
	CONNECTICUT				8,343	349	18,441	None		
	DELAWARE				3,687	177	13,530	None		
	FLORIDA				6,951	141	14,993	None		
	GEORGIA				1,655	134	4,810	None		
	HAWAII				89	5	267	None		
	ILLINOIS				322,339	12,913	1,138,512	None		
	INDIANA				241,129	10,775	665,767	None		
	KENTUCKY				269,610	10,538	524,565	None		
	LOUISIANA				2,164	52	4,768	None		
	MAINE				10,089	246	23,876	None		
	MARYLAND				40,576	1,429	120,402	None		
	MASSACHUSETTS				9,921	406	22,537	None		
	MISSISSIPPI				3,931	159	7,113	None		
	NEW HAMPSHIRE				5,373	218	13,475	None		
	NEW JERSEY				20,310	728	51,483	None		
	NORTH				10,322	758	16,755	None		

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	CAROLINA									
	PENNSYLVANIA				475,873	14,402	1,357,225			
	RHODE ISLAND				1,035	63	1,806	None		
	SOUTH CAROLINA				4,070	143	8,860	None		
	TENNESSEE				20,074	1,655	45,819	None		
	VERMONT				31,769	571	68,624	None		
	VIRGINIA				89,213	3,063	233,807	None		
	WEST VIRGINIA				28,465	1,185	62,484	None		
	WISCONSIN				1,517,522	30,810	3,673,619	None		
	Subtotal	-	-	-	3,143,768	91,538	8,139,129			
Tier II: States with <100,000 lbs seed production (2007)	COLORADO	1,815	8	-	861,053	8,648	2,887,865	Minor	TUGrestrictions,plus,if fieldiswithin165ftofconventionalseedproduction,then<10%bloomcut required	Not Applicable
	IOWA	-	5	-	830,440	22,040	3,054,729	Minor		
	KANSAS	342	5	22,430	793,140	9,643	2,986,134	Minor		
	MICHIGAN	-	10	15,610	698,595	16,431	1,707,036	Minor		
	MINNESOTA	611	17	63,461	944,775	20,398	2,671,173	Minor		
	MISSOURI	399	19	40,540	295,021	8,229	782,847	Minor		
	NEBRASKA	545	29	21,216	1,085,921	14,820	3,955,881	Minor		
	NEWMEXICO	310	15	29,907	236,103	4,272	1,176,242	Minor		
	NEWYORK	27	3	6,180	450,144	7,707	1,119,421	Minor		
	NORTH DAKOTA	-	6	34,784	1,457,604	8,985	3,072,682	Minor		
	OHIO	-	1	-	437,658	15,354	1,256,174	Minor		
	TEXAS	546	24	79,885	153,763	2,391	721,303	Minor		

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	Subtotal	4,595	142	314,013	8,244,217	138,918	25,391,487	Minor			
Tier III: States with >100,000 lbs seed (2007)	ARIZONA	5,206	53	1,902,669	257,407	943	1,968,043	Major	**If 2007 census indicated NO in-county seed production, then:**	**If 2007 census indicated seed production in county, then:**	No RRA forage planting allowed
	CALIFORNIA	36,625	114	19,083,458	986,982	3,587	7,057,014	Major			
	IDAHO	12,788	92	9,346,709	1,037,520	8,817	4,254,543	Major	See Census Criteria (See Appendix B for county list)	TUG restrictions and GPS coordinate reporting; if new field is within 165 ft of conv.seed production, then 10% bloom cut required	
	MONTANA	10,338	80	3,729,635	1,868,756	9,711	3,936,445	Major			
	NEVADA	6,498	19	4,237,101	274,004	1,128	1,217,586	Major			
	OREGON	4,959	32	3,183,375	428,812	3,569	1,777,894	Major			
	OKLAHOMA	2,004	29	281,121	334,990	3,781	1,131,938	Major			
	SOUTH DAKOTA	6,014	47	428,447	1,996,599	12,653	4,414,338	Major			
	UTAH	3,803	54	2,077,813	548,570	7,780	2,172,218	Major			
	WASHINGTON	17,127	82	10,860,608	448,588	4,294	2,192,001	Major			
	WYOMING	10,548	62	5,915,816	674,284	4,007	1,696,438	Major			
	Subtotal	115,910	664	61,046,752	8,856,512	60,270	31,818,458				
	Grand Total	120,505	806	61,360,765	20,244,497	290,726	65,349,074				

RRA SEED PRODUCTION RESTRICTIONS

The National Alfalfa and Forage Alliance (NAFA) used current science and extensive stakeholder input to design the "Best Management Practices (BMP) for Roundup Ready Seed Production" (See Appendix C in this ER for additional details on BMPs for Roundup Ready® Alfalfa Seed Production). These BMP have been adopted by the industry as standards for any future RRA seed production as part of an overall stewardship program designed to ensure coexistence of various alfalfa hay and seed markets. All RRA seed grower contracts require full adherence to the NAFA BMP, a type of identity preserved process-based seed stewardship, which includes but is not limited to the following measures:

- RRA seed field location reporting to official seed certification agencies
- Field and isolation zone inspection by official seed certification agencies
- Equipment cleaning prior to and after use
- Segregated and uniquely identified seed handling and storage
- Planting stockseed labeling
- FGI RRA seed grower education and contracting
- Field termination reporting
- Seed company monitoring of compliance
- Annual third-party review of efficacy of BMP
- Other

FGI has individual seed-producer farmer partners who have asked for the opportunity to produce RRA seed crops.

Partial deregulation of RRA would include seed production that is restricted to eight defined seed grower consortia (Table 1-2). FGI has determined that each of these individual consortia could meet or exceed the National Alfalfa & Forage Alliance BMP for RRA Seed Production (NAFA, 2008a) parameters and the proposed partial deregulation enhancements to isolation distance described below (See Appendix C and Table 1-2).

1) **Seed Identification**: Stockseed container to be clearly labeled as containing RRA trait seed. Grower seed contracts and official field reporting will notify each seed grower regarding the measures imposed for seed growing.

2) **Implement all NAFA BMP with Isolation Enhancement**

   a. All BMP measures will be followed, documented, monitored and enforced for compliance by FGI or its representatives. In addition, each field will be inspected annually by the local seed certification agency, confirming minimum isolation standards for that production year.

   b. Measures will set the enhanced, minimum, isolation requirements for RRA seed fields as follows. The minimum required isolation from conventional, commercial seed fields will be 4 miles and 1 mile, when honeybees or leafcutter bees are the managed pollinating species, respectively.

   c. The potential for gene flow at NAFA BMP isolation is de minimis (Van Deynze et al. 2008) and this measure's proposed enhancement of isolation distance would further ensure de minimis gene flow potential into conventional seed crops should they be present.

3) **Geographic Restrictions**:

   a. Only eight pre-authorized, physically-isolated locations for RRA seed production will be allowed. Each location of proposed seed growing is composed of one to three large seed growers who will act together to manage isolation control within a local, informal RRA seed grower consortium.

Table 1-2 Eight Seed Grower Consortia

Grower Consortium	Counties and State	Number of requesting growers	Approximate number of initial acres (2010-2011)	Managed pollinator bee species	Seed harvest equipment status, ownership	Current isolation distance to conventional seed	NAFA Best Practices minimum isolation distance	Partial Deregulation Isolation, minimum distance
A. Northern California	Lassen, CA	1	300	leafcutter	On-Farm	>5mi	900 ft	1 mi
B. Central California	Kings, Kern, Fresno, CA	2	2,000	Honeybee +leafcutter	On-farm	4 mi	3 mi	4 mi
C. Colorado	Mesa, CO	3	1,000	leafcutter	On-farm	>10 mi	900 ft	1 mi
D. Eastern Idaho	Oneida, Manidoka, Twin Falls, ID		500	leafcutter	On-farm	1 mi	900 ft	1 mi
E. Western Idaho	Ada, Canyon, Payette, ID	3	2,000	leafcutter	On-farm	1 mi	900 ft	1 mi
F. Nevada	Humbolt, Pershing, NV	2	600	leafcutter	On-farm	2 mi	900 ft	1 mi
G. Texas	Carson, Castro, Donley, Gray, Lamb, Ochiltree, Roberts, Swisher, TX	1	500	leafcutter	On-farm	>10 mi	900 ft	1 mi
H. Utah	Box Elder, Cache, Millard, Weaver, UT	3	500	leafcutter	On-farm	5 mi	900 ft	1 mi

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1.2 RATIONALE FOR CREATION OF RRA

Alfalfa is a small seeded perennial forage crop that competes with annual weeds during establishment and with annual and perennial weeds in established stands. With irrigated alfalfa stands, weed seeds in irrigation water can reinfest the stand with weed seeds with every irrigation event. Weed infestation increases the risk of successful establishment and weeds generally compete with alfalfa for light, water, and nutrients. Weeds can have an adverse affect on the quality of harvested forage and effectively shorten the productive life of the alfalfa stand. RRA offers alfalfa growers a simpler, more effective, more flexible, and less expensive herbicide alternative for weed control. Current weed control programs in alfalfa production have serious limitations because certain weed species are difficult to control. Certain of these difficult to control weeds are poisonous and/or toxic to livestock. Glyphosate applications to RRA will offer flexibility in timing of weed control, including preplant, preemergence and/or postemergence applications. In contrast to most other commonly used alfalfa herbicides, glyphosate can safely be applied at virtually any stage of GT alfalfa development. The use of GT alfalfa can help increase alfalfa forage yield and forage quality through better weed control (Rogan and Fitzpatrick, 2004, pp. 20-21; Medlin and Siegelin, 2001).

Glyphosate is not used for in-crop weed control in conventional alfalfa (those without glyphosate tolerance) because it damages the plants. With GT alfalfa, growers have another option for weed control.

1.3 SCOPE OF ENVIRONMENTAL ISSUES ADDRESSED

During the lawsuit discussed above, certain specific issues were identified by the court as requiring additional NEPA analysis by APHIS (USDC, 2007). These primary issues are described below and are addressed in the Affected Environment and Environmental Consequences sections of this ER. Other issues identified by APHIS in the draft EIS are also addressed to the extent they are relevant to the proposal for partial deregulation to ensure full disclosure and analysis of any potential impacts associated with partial deregulation of RRA under the proposed measures. Many of the citations herein are to the draft EIS discussions of the basic facts regarding alfalfa, its weed threats and cultivation.

1.3.1 Gene transmission to non-genetically engineered alfalfa

Alfalfa is a perennial crop and is typically replanted every three to six years. The crop is typically harvested for forage three to eight times per year, depending on location and seasonal climate. Most alfalfa in the U.S. is harvested in the late vegetative stage (pre-bloom) to optimize

yield and nutritional quality. Forage quality begins to drop dramatically in hay harvested after the flowering stage, and continues to deteriorate as the crop further matures toward pod/seed set (USDA APHIS, 2009, p. 40). Hay harvested after 10 percent bloom is generally of poor quality for feed and has low market value (USDA APHIS, 2009, p. G-6). This leaves little opportunity for pollination among forage crops. Alfalfa is exclusively pollinated by bees which normally pollinate other alfalfa plants growing in close proximity. However, pollinations at greater distances can occur (e.g, less than 1 to greater than 3 miles depending upon the bee species).

In contrast, growers promote flowering and seed ripening in commercial seed fields. In most fields, flower buds begin to form on stems approximately 4 to 6 weeks after field mowing during long-day photoperiods and warm weather. Once alfalfa begins flowering, it flowers indeterminately, and its duration depends on moisture, temperature, and other factors (Rogan and Fitzpatrick, 2004). Ripe seed, viable for germination, is formed 5 to 6 weeks after pollination (i.e., 9 to 12 weeks total after mowing). Seed harvested before this stage is not viable.

Cross-pollination between RRA and conventional or organic alfalfa crops could potentially result in the inadvertent presence of GE material in conventional or organic alfalfa hay intended for a market with specific or zero tolerance for the presence of GE material. Putnam (2006) estimated that the GE sensitive hay market is approximately 3 to 5 percent of the total market. He estimated that the majority of the market (95 to 97 percent) is composed of growers that may either adopt RRA varieties and/or are not likely to be GE sensitive in their buying decisions.

Detailed analysis of the potential for gene transmission from RRA has been conducted. Potential impacts from both hay and seed production on organic and conventional hay and seed production, other Medicago crops, and feral populations of alfalfa are analyzed in Sections 3.3 through 3.8 of this ER. A study of the topic was separately published (Van Deynze et al., 2008).

1.3.2 Socioeconomic impacts

The court found that APHIS failed to analyze in its initial EA the socio-economic impacts of deregulating RRA on organic and conventional farmers. Therefore, further analysis was conducted and is discussed in Sections 3.15 of this ER.

1.3.3 Consumer's choice to consume non-GE food

The court found that APHIS failed to analyze the possibility that deregulation of RRA would degrade the human environment by eliminating a consumer's choice to consume, or a grower's

choice to grow, non-GE food. Therefore, further analysis was conducted and is discussed in Section 3.10 of this ER.

1.3.4 Potential for development of glyphosate-resistant (GR) weeds

As the adoption of GT crops has grown, the use of glyphosate has increased (National Research Council [NRC], 2010, Figures S-1, S-2, and S-3; Young, 2006). Concerns have been expressed that increased use of glyphosate may lead to development of GR weeds. Further analysis was conducted and is discussed in Sections 2.4 and 3.11 of this ER.

1.3.5 Cumulative effects of increased use of glyphosate

Further analysis of cumulative impacts from increased use of glyphosate was conducted and is discussed in Section 4 of this ER.

1.4 FEDERAL REGULATORY AUTHORITY – COORDINATED FRAMEWORK

Interagency coordination in scientific and technical matters is the responsibility of the federal Office of Science and Technology Policy (OSTP), which was established by law in 1976. A large part of the OSTP's mission is "to ensure that the policies of the Executive Branch are informed by sound science" and to "ensure that the scientific and technical work of the Executive Branch is properly coordinated so as to provide the greatest benefit to society" (OSTP, undated).

In 1986, the OSTP published a "comprehensive federal regulatory policy for ensuring the safety of biotechnology research and products", the *Coordinated Framework for the Regulation of Biotechnology* (Coordinated Framework) (OSTP, 1986). The OSTP concluded that the goal of ensuring biotechnology safety could be achieved within existing laws (OSTP, 1986).

The Coordinated Framework specifies three federal agencies responsible for regulating biotechnology in the U.S.: USDA's APHIS, the EPA, and the FDA. APHIS regulates GE organisms under the PPA of 2000. EPA regulates plant-incorporated protectants and herbicides used with herbicide-tolerant crops under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and Federal Food, Drug, and Cosmetic Act (FFDCA). FDA regulates food (including animal feed, but not including meat and poultry, which is regulated by USDA), including food and feed produced through biotechnology, under the authority of the FFDCA. Products are regulated according to their intended use and some products are regulated by more than one agency. Together, these agencies ensure that the products of modern biotechnology are safe to grow, safe to eat, and safe for the environment. USDA, EPA, and

FDA enforce agency-specific regulations to products of biotechnology that are based on the specific nature of each GE organism.

In 2001, in a joint Council on Environmental Quality (CEQ)/OSTP assessment of federal environmental regulations pertaining to agricultural biotechnology, the CEQ and OSTP found that "no significant negative environmental impacts have been associated with the use of any previously approved biotechnology product" (CEQ/OSTP, 2001, p. 1).

For RRA, the plant is reviewed by USDA and FDA, whereas EPA is responsible for registering the use of the glyphosate herbicide and establishing a tolerance for allowable glyphosate residues.[12] As indicated herein, although certain issues such as weed resistance and impacts of glyphosate on animals or plants are addressed by EPA (not APHIS), this ER nevertheless addresses those issues.

1.4.1 USDA regulatory authority

The APHIS BRS mission is to protect U.S. agriculture and the environment using a dynamic and science-based regulatory framework that allows for the safe development and use of GE organisms. Under its authority from the PPA, APHIS regulates the introduction (importation, interstate movement, or release into the environment) of certain GE organisms and products.[13] A GE organism is presumed to be a regulated article if the donor organism, recipient organism, vector, or vector agent used in engineering the organism belongs to one of the taxa listed in the regulation[14] and is also presumed to be a plant pest. APHIS also has authority under these rules to regulate a GE organism if it has reason to believe that the GE organism may be a plant pest or APHIS does not have sufficient information to determine that the GE organism is unlikely to pose a plant pest risk.[15]

Under APHIS' regulations a person may petition APHIS to evaluate submitted data and determine that a particular regulated article is unlikely to pose a plant pest risk, and, therefore, should no longer be regulated.[16] The petitioner is required to provide information related to plant pest risk that the agency may use to determine whether the regulated article is unlikely to

[12] Under the FFDCA and associated regulations, EPA sets a tolerance, or maximum residue limit, for pesticide treated food and feed items. A tolerance is the amount of pesticide residue allowed to remain in or on each treated food commodity. The tolerance is the residue level that triggers enforcement actions. That is, if residues are found above that level, the commodity will be subject to seizure by the government.

[13] 7 C.F.R. §340.

[14] 7 C.F.R. §340.2.

[15] 7 C.F.R. §340.1.

[16] 7 C.F.R. §340.6. entitled "Petition for determination of non-regulated status".

present a greater plant pest risk than the unmodified organism.[17] If the agency determines that the regulated article is unlikely to pose a plant pest risk, the GE organism will be granted non-regulated status. In such a case, APHIS authorizations (i.e. permits and notifications) would no longer be required for environmental release, importation, or interstate movement of the non-regulated article or its progeny.

It was under these regulations that Monsanto/FGI submitted the petition for a determination of non-regulated status for event J101/J163 (Rogan and Fitzpatrick, 2004). J101/J163 alfalfa were considered regulated because they contain non-coding deoxyribonucleic acid (DNA) segments derived from plant pathogens and the vector agent used to deliver the transforming DNA is a plant pathogen (See Section 3.1 for a discussion of these concepts) (USDA APHIS, 2005, p. 5).

1.4.2 EPA regulatory authority

EPA is responsible for regulation of pesticides (including herbicides such as glyphosate) under the FIFRA.[18] FIFRA requires that all pesticides be registered before distribution, sale, and use, unless exempted by EPA regulation. Before a product is registered as a pesticide under FIFRA, it must be shown that when used in accordance with the label, it will not result in unreasonable adverse effects on the environment.

Under the FFDCA, as amended,[19] pesticides added to (or contained in) raw agricultural commodities generally are considered to be unsafe unless a tolerance or exemption from tolerance has been established. EPA establishes residue tolerances for pesticides under the authority of the FFDCA. EPA is required, before establishing a pesticide tolerance to reach a safety determination based on a finding of reasonable certainty of no harm under the FFDCA, as amended by the Food Quality Protection Act of 1996 (FQPA). The FDA enforces the tolerances set by the EPA. EPA approved the use of glyphosate over the top of RRA on June 15, 2005. The use of glyphosate over the top of RRA did not require an increase in the existing glyphosate residue tolerance of 400 ppm in the animal feed, non-grass crop group; this tolerance supports the feeding of alfalfa forage that has been treated with glyphosate to livestock. EPA issued a new glyphosate tolerance for alfalfa seed of 0.5 ppm on February 16, 2005.[20]

[17] 7 C.F.R. §340.6(c)(4).
[18] 7 U.S.C. §136 et seq.
[19] 21 U.S.C. §301 et seq.
[20] 40 C.F.R. §180.364; 70 Fed. Reg. 7861 (Feb. 16, 2005).

1.4.3 FDA regulatory authority

FDA, which has primary regulatory authority over food and feed safety, has published a policy statement in the Federal Register concerning regulation of products derived from new plant varieties, including those genetically engineered (FDA, 1992). Under this policy, FDA uses a consultation process to ensure that human food and animal feed safety issues or other regulatory issues (e.g. labeling) are resolved prior to commercial distribution of a bioengineered food. Monsanto/FGI submitted a food and feed safety and nutritional assessment summary for RRA to FDA in October 2003. FDA completed its consultation process in 2004 (Tarantino, 2004; Hendrickson and Price, 2004). FDA's analysis and related impacts are discussed in Section 3.10.

1.5 THE NATIONAL ORGANIC PROGRAM AND BIOTECHNOLOGY

Congress passed The Organic Foods Production Act (OFPA) of 1990 to avoid the confusion and misrepresentation then taking place in the "organic" marketplace.[21] The OFPA required the USDA to establish a National Organic Program (NOP) to develop uniform standards and a certification process for those producing and handling food products offered for sale as "organically produced."[22] The OFPA requires certification under the NOP, which was finalized in 2000, to be process-based.[23] "The certification process does not guarantee particular attributes of the end product; rather it specifies and audits the methods and procedures by which the product is produced" (Ronald and Fouche, 2006). The NOP defines certain "excluded methods" of breeding that cannot be used in organic production, describing them as "means that are not possible under natural conditions or processes."[24] Along with genetic engineering, three other modern breeding techniques are specified as "excluded methods" in the regulations.[25] Thus, a certified organic grower cannot intentionally plant seeds that were developed by these specific excluded methods. However, because "organic" is based on process and not product, the mere presence of plant materials produced through excluded methods in a crop will not jeopardize the integrity of products labeled as organic, as long as the grower follows the required organic production protocol. Also, other modern breeding methods -

[21] 7 U.S.C. § 6501 et seq.
[22] 7 C.F.R. Part 205, announced at 65 Fed. Reg. 80548 (Dec. 21, 2000).
[23] 7 U.S.C. §6503(a).
[24] 7 C.F.R. §205.2.
[25] *Id.*

for example, induced radiation or chemical mutagenesis - are not specified as excluded methods by the NOP (discussed in Section 3.1.1).

All organic growers' production plans must be approved by an organic certifying agent before the farm can be certified as "organic."[26] Such plans must include, among other things, steps the organic grower is taking to avoid what the NOP refers to as "genetic drift" from any neighboring crops using excluded methods.[27] Certification must include on-site inspections of the farm to verify the procedures set forth in the organic production plan.[28]

Thus, the NOP recognizes the coexistence of organic growers with neighboring growers who may choose to grow products developed using certain methods of biotechnology. So long as an organic grower follows an approved organic method of production that seeks to avoid contact with these specific biotechnology-derived crops, if some residue of the biotechnology-derived plant material is later found in the organic crop (or food produced from it), neither the crop (or food) nor the organic farm is in danger of losing its organic status. According to the standards established by the NOP, no grower or seed producer should lose organic certification due to inadvertent transmission of genetic material from a genetically engineered crop.

In the context of the genetic drift discussion, in the preamble of the NOP regulations, USDA emphasized that it is the use of excluded methods as a production method that is prohibited, not the mere presence of a product of excluded method:

> It is particularly important to remember that organic standards are process based. Certifying agents attest to the ability of organic operations to follow a set of production standards and practices that meet the requirements of the Act and the regulations. This regulation prohibits the use of excluded methods in organic operations. The presence of a detectable residue of a product of excluded methods alone does not necessarily constitute a violation of this regulation. As long as an organic operation has not used excluded methods and takes reasonable steps to avoid contact with the products of excluded methods as detailed in their approved organic system plan, the unintentional presence of the products of excluded methods should not affect the status of an organic product or operation.[29]

The NOP calls for testing only if there is "reason to believe" that a grower has used excluded methods.[30] The preamble states that a "reason to believe" may be triggered by situations such

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[26] *See* 7 C.F.R. Part 205, Subpt. E.
[27] *See id.* at 205.201; 65 Fed. Reg. 80547, 80556 (Dec. 21, 2000) (discussing "genetic drift").
[28] 7 C.F.R. §205.403.
[29] 65 Fed. Reg. 80547, 80556 (Dec. 21, 2000).
[30] 7 C.F.R. §205.670(b).

as a formal, written complaint to the certifying agent regarding the practices of a certified organic operation; the proximity of a certified organic operation to a potential source of drift; or the product from a certified organic operation being unaffected when neighboring fields or crops are infested with pests.[31]

This testing provision does not establish a zero tolerance standard for the presence of products of excluded methods in organically labeled food. Rather, it serves as a warning that excluded methods may have been used: "Any detectable residues of. . . a product produced using excluded methods found in or on samples during analysis will serve as a warning indicator to the certifying agent."[32]

> [T]hese regulations do not establish a "zero tolerance" standard. . . [A] positive detection of a product of excluded methods would trigger an investigation by the certifying agent to determine if a violation of organic production or handling standards occurred. The presence of a detectable residue alone does not necessarily indicate use of a product of excluded methods that would constitute a violation of the standards."[33]

Only if the organic producer intentionally used excluded methods of crop production will that producer be subject to suspension or revocation of organic certification.

Indeed, since the time GE crops were introduced in the U.S. in the mid-1990s, organic markets have grown and expanded (Smith, 2010b, p. 10).

1.5.1 Non-GMO Project working standard

The Non-GMO[34] Project is a non-profit organization created by leading members of the organic industry to "offer consumers a consistent non-GMO choice for organic and natural products that are produced without genetic engineering or recombinant DNA technologies" (Non-GMO Project, 2010a). The Non-GMO Project has created a working standard to implement its goal. The standard sets action thresholds for "GMO" (GE) adventitious presence for certain products. If these action thresholds are exceeded, the participant must investigate the cause of the exceedance and take corrective action (Non-GMO Project, 2010, p. 13). The standard sets a threshold of 0.25 percent for GE material for the presence of GE traits in non-GE seeds (p. 28), and a 0.9 percent threshold for non-GE food or feed (p.14).

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[31] *See* 65 Fed. Reg. 80547, 80629 (Dec. 21, 2000).
[32] *Id.* at 80628.
[33] *Id.* at 80632.
[34] GMO stands for genetically modified organism.

1.5.2 Growth in organic and GE farming

Expansion of organic farming has succeeded at the same time as the growth of GE crops. Consumer demand for organically produced goods "has shown double-digit growth for well over a decade" and organic products "are now available in nearly 20,000 natural food stores and three of four conventional grocery stores." Organic products "have shifted from being a lifestyle choice for a small share of consumers to being consumed at least occasionally by a majority of Americans" (USDA Economic Research Service [ERS], 2009c).

1.6 COEXISTENCE IN U.S. AGRICULTURE

1.6.1 Coexistence and biotechnology

Coexistence of different varieties of sexually compatible crops has long been a part of agriculture, especially in seed production, where large investments are made in developing new varieties and high seed purity levels are required by the Federal Seed Act's implementing regulations.[35] The aspect of coexistence most relevant to this document is that related to specific methods of crop production. In this context, coexistence refers to the "concurrent cultivation of conventional, organic, and genetically engineered (GE) crops consistent with underlying consumer preferences and choices" (USDA Advisory Committee, 2008). The differences among these crops that are particularly relevant to coexistence in this ER are in the types of breeding methods (sometimes referred to as "genetic modifications") that are associated with each of these three types of crop production.

"**Genetic engineering**" is defined by APHIS regulations as "the genetic modification of organisms by recombinant DNA techniques."[36] Recombinant DNA (rDNA) techniques are discussed in Section 3.1.1 of this ER. While there are many ways to genetically modify a crop, the APHIS definition of GE crops applies only to those developed using rDNA techniques, which are among the more modern breeding methods.

Organic crops are those produced in accordance with the requirements of the NOP, discussed in Section 1.5.

Conventional crops are simply those that are neither GE nor organic. They may be commodity crops (mass produced), or they may be identity preserved, with some characteristic tailored for a specific end user. Identity-preserved usually refers to a "specialty, high-value, premium or niche market" (Massey, 2002). One type of identity preserved product that has

[35] 7 C.F.R. § 201
[36] 7 C.F.R. §340.1

been produced since the introduction of GE crops is "non-GE"; however, there are no mandatory standards governing the use and/or marketing of "non-GE" products. (USDA Advisory Committee, 2008).

Farmers who want to maximize their profitability must decide whether the higher prices (premiums) they may receive for organic or identity-preserved crops are sufficient to offset the added managerial costs of producing these crops. As researchers have noted, "Although yields on organic farms are sometimes less than those of conventional systems, price premiums make it an attractive option for growers looking for specialized markets and a higher-value product" (Ronald and Fouche, 2006).

1.6.2 USDA position on coexistence and biotechnology

It is USDA's position that all three methods of agricultural production described above can provide benefits to the environment, consumers, and the agricultural economy (Smith, 2010b).

1.6.3 Coexistence in U.S. agriculture

The USDA Advisory Committee on Biotechnology and 21st Century Agriculture who reported that "coexistence among the three categories of crops is a distinguishing characteristic of U.S. agriculture, and makes it different from some other parts of the world," expressed its belief that U.S. agriculture supports coexistence, and recommended continued government support of coexistence (USDA Advisory Committee, 2008). Among the Committee's findings:

- The U.S. is the largest producer of GE crops in the world.
- The U.S. is one of the largest producers of organic crops in the world.
- The U.S. is one of the largest exporters of conventionally-grown, identity preserved, non-GE crops in the world.
- Some U.S. farmers currently are producing a combination of organic, conventional, and GE crops on the same farm.

Among the coexistence-enabling factors the Committee identified is the existing "legal and regulatory framework that has enabled different markets to develop" without foreclosing the ability of "participants in the food and feed supply chain to establish standards and procedures (e.g., not setting specific mandatory adventitious presence (AP) thresholds and having process-based rather than product-based organic standards)." At the same time, development of practices and testing methods that allow for voluntary thresholds has also enabled coexistence (USDA Advisory Committee, 2008).

As APHIS has previously observed, "studies of coexistence of major GE and non-GE crops in North America and the European Union (E.U.) demonstrated that there has been no significant gene flow from GE crops and that GE and non-GE crops are coexisting with minimal adverse economic effects" (Smith, 2010b, pp. 11-12) (citing Gealy et al., 2007; Brookes and Barfoot, 2003; Brookes and Barfoot, 2004(a) and (b), and Walz 2004). In addition, "the agricultural markets and local entities have addressed coexistence through contractual arrangements, management measures, and marketing arrangements. This market-based approach to coexistence has created economic opportunities for all kinds of producers of agricultural products." (*Id.* p. 9). RRA is one of fifteen GT events previously deregulated by USDA. See APHIS, EPA, Petitions of Non-Regulated Status Granted or Pending by APHIS as of February 2, 2010, http://www.aphis.usda.gov/brs/not_reg.html).

1.7 ROLE OF THE NATIONAL ACADEMIES IN AGRICULTURAL BIOTECHNOLOGY

The analyses in this ER are based on published, peer-reviewed scientific papers; federal government assessments; assessments from international agencies; information from specialists from many universities; data collected by Monsanto/FGI under controlled conditions; and information from other relevant sources. One resource used for this ER is the National Academies (NA), a private, non-profit institution that advises the nation on scientific and technical matters. It consists of the National Academy of Sciences (NAS), the National Academy of Engineering, the Institute of Medicine (IM) and the National Research Council (NRC) (NA, 2010). Scientists, engineers and health professionals are elected by their peers to the academy and serve *pro bono*. Reports are prepared by committees of members with specialized expertise and reviewed by outside anonymous experts (Alberts, 1999). NA reports, as well as the scientific studies used in those reports, are used as applicable throughout this document.

The NA has been active in studies related to agricultural biotechnology since the 1970s and works cooperatively with federal agencies, and its reports have provided guidance and recommendations for process improvement to regulatory agencies (Alberts, 1999). The NRC 1989 guidelines for field testing of genetically engineered organisms were used as the basis for agency procedures for field trials (Alberts, 1999; NRC, 1989). In studies in 1987 and 2000 the NRC emphasized that the characteristics of the modified organism should be the object of a risk assessment, and not the methods by which the modifications were accomplished; and that the risks associated with recombinant DNA techniques are the same in kind as risks from other types of genetic modification (NRC, 1987; NRC, 2000). This position was re-iterated in a 2004

study prepared jointly by the IM and the NRC. Whether such compositional changes result in unintended health effects is dependent on the nature of the substances altered and the biological consequences of the compounds. To date, "no adverse health effects attributed to genetic engineering have been documented in the human population" (Institute of Medicine and National Research Council [IM/NRC], 2004, p. 8). In a 2002 report, the NRC "found that the current standards used by the federal government to assure environmental safety of transgenic plants were higher than the standards used in assuring safety of other agricultural practices and technologies" (NRC, 2002). The NRC reports that, while biotechnology is not without risk, since the first commercial introduction of transgenic plants, "biotechnology has provided enormous benefits to agricultural crop production" (NRC, 2008). NRC's latest report on biotechnology in agriculture evaluates the impact of genetically engineered crops on farm sustainability (NRC, 2010). The authors concluded that an understanding of impacts on all farmers will help ensure that GE technology contributes to sustainability and that commercialized GE traits to date, when used properly, "have been effective at reducing pest problems with economic and environmental benefit to farmers" (NRC, 2010).

1.8 ALTERNATIVES

In addition to the alternative of implementing the partial deregulation measures (Alternative 2), this ER considers the alternative of full regulation (Alternative 1).

1.8.1 Alternative 1 – No Action

In conducting NEPA review, agencies consider a no action alternative, which provides a baseline against which action alternatives can be evaluated. This ER identifies the no action alternative as a return to full regulation – or the *status quo* when the petition for deregulation of RRA was initially submitted. Under this alternative, the introduction of RRA would be fully regulated and would require permits issued or notifications acknowledged by APHIS until APHIS completes its EIS and issues a Record of Decision (ROD) regarding whether to deregulate RRA. For purposes of this analysis, we assume that Alternative 1 would not involve widespread RRA cultivation, and instead would contemplate a return to conventional alfalfa crops or to crops other than alfalfa.[37]

[37] This ER does not address the acres of RRA planted prior to March 30, 2007, and cultivated pursuant to conditions required by the district court and implemented by APHIS by administrative order. These acres are reaching the end of their productive lives and will be removed within the next few years under either Alternative. Because their acreage and expected lifespan is so small, and because their impacts would be identical under either Alternative, the analysis of these limited impacts would not be meaningful within the scope of this ER.

1.8.2 Alternative 2 – Partial Deregulation

Under this alternative APHIS would implement the proposed measures described in Section 1.1.3.

SECTION 2.0 AFFECTED ENVIRONMENT

2.1 ALFALFA CHARACTERISTICS

Alfalfa (*Medicago sativa* L.) is a deep-rooted and short-lived perennial plant considered to be the "Queen of Forages" due to its high nutritional content for cattle, sheep and horses (USDA APHIS, 2009, p. 18).

2.1.1 Growth

Alfalfa is recognized as a widely adapted crop, growing in all continental States, as well as Alaska and Hawaii. Alfalfa initially grows from seed, but after each harvest or winter it will re-grow from buds arising from the perennial crown/root structure. As alfalfa grows, yield (i.e. above ground biomass) increases until alfalfa yield peaks at full bloom. However, juvenile vegetative alfalfa vegetative alfalfa plants have the highest nutritional value and that nutritional value decreases as the plant approaches full flower. The vegetative growth interval during most of the year is 22 to 40 days. The crop is typically harvested for forage three to eight times per year, depending on location and seasonal climate. The alfalfa plant grows until stopped by a hard freeze. Fields grown for forage production are typically maintained for 3 to 6 years or longer in some areas (USDA APHIS, 2009, p. 18-19).

2.1.2 Pollination

Alfalfa is predominantly cross-pollinated and the flowers depend entirely on bees for cross-pollination. Alfalfa requires bees to physically "trip" flowers to release pollen for egg fertilization and seed production (refer to Section 2.2.3) (USDA APHIS, 2009, p. 19).

Alfalfa is exclusively insect pollinated (Mallory-Smith and Zapiola, 2008). The flowers depend on bees for cross-pollination. Alfalfa seed farmers must stock bees to ensure pollination because most regions that cultivate alfalfa seed do not have naturally occurring populations of effective alfalfa pollinators. Forage farmers do not stock bees, however, because they do not want or need pollination of their fields (USDA APHIS, 2009, p. 94; Rogan and Fitzpatrick, 2004). Leafcutter bees (Megachile rotundata F.) are typically used to pollinate alfalfa seed production fields in the cooler Pacific Northwest (PNW), and honey bees (Apis mellifera) are primarily used in the Desert Southwest. However, a few growers in niche regions like southern Washington use alkali bees (Nomia melanderi) due to their unique geography and climate (USDA APHIS, 2009, p. 19). Alfalfa pollen is not carried by the wind; it is not wind-pollinated. Severe environmental conditions such as, heavy winds in combination with drought, may sometimes

cause flowers to trip and self-pollinate. Although rare, self-pollinated seeds have inferior vigor and germination due to genetic inbreeding depression in alfalfa (Teuber, 2007).

Pollen-mediated gene flow decreases exponentially as the distance from the pollen source increases (Mallory-Smith and Zapiola, 2008). However, the type of pollinator determines the extent. All bees have a limited range over which they will search to efficiently collect pollen; most nectar or pollen foraging occurs close to the nest when flowers are present. The maximum foraging radius for each of the three commercially available bee species (honey bees, leafcutter bees, and alkali bees) depends heavily on the abundance of nectar and pollen resources. Leafcutter bees have the shortest routine foraging radius of less than a 1/4 mile. The honey bee and alkali bee having a forging range of 1 to 3 miles (Arnett, 2003; Gathmann and Tscharntke, 2002; Hammon et al., 2006; Teuber et al., 2005). Honey bees may infrequently transport alfalfa pollen and effect pollination up to 3 miles from the source (St. Amand et al., 2000; Teuber et al., 2004; Hammon et al. 2006). Honey bees are predominantly nectar collectors and as such they tend to avoid the tiny alfalfa flowers when other sources of nectar flowers are available. When visiting alfalfa flowers, honey bees are known as inefficient pollinators because they predominantly "side-feed" solely for nectar, i.e., they leave the flower closed (un-tripped) and un-pollinated. Feral honey bees and native bees including *Bombus* spp., *Osmia* spp., *Agapostomen* spp. and *Megachile* spp. can also be found visiting alfalfa flowers in varying numbers. These species may sometimes pollinate alfalfa flowers but their importance in alfalfa pollination is minor (USDA APHIS, 2009, p. O-5; Hammon et al., 2006; Arnett, 2002).

2.2 ALFALFA PRODUCTION

2.2.1 Forage production, general

Alfalfa is among the most important forage crops in the U.S., with more than 21 million acres in cultivation. Recognized as the oldest plant grown solely for forage, alfalfa has been used as livestock feed because of its high protein and low fiber content. Alfalfa is ranked fourth on the list of most widely grown U.S. crops by acreage and is ranked third among agricultural crops in terms of value (USDA APHIS, 2009, p. 17). The harvested acreage of alfalfa harvested for forage (dry hay) was approximately 21 million acres in 2009, which generated 71 million tons of hay at an average yield of 3.35 tons per acre (USDA ERS, 2010a and 2010b). Over the last 60 years (since 1951), harvested alfalfa hay acreage in the U.S. has ranged between 20.7 acres (2010) and 29.8 million (1957) (USDA ERS, 2010a). From 1951 to 2009 (latest year available), total U.S. production (dry) has ranged between 46.8 million tons (1951) and 91.9 million tons

(1986) (USDA ERS, 2010b). Since 1950, yields generally increased until about the mid-1980s; since then yields in most years have been around 3.3 tons per acre. The total acreage of harvested alfalfa has generally been declining since the mid-1980s, with 2010 the lowest year since 1950 (USDA ERS, 2010a). The production decreases are due to alfalfa's use in crop rotation declining in the U.S., and the increased use of corn silage as a source of forage in dairy diets coupled with the decline in dairy (milk) prices paid to farmers. Alfalfa requires different management, equipment, and labor schedules than other major cropping systems such as corn and soybeans. Transportation of bulky alfalfa hay or haylage to distant markets may be prohibitively expensive (USDA APHIS, 2009, p. 34). In the 2009/2010 season (May 2009 to April 2010), the average price farmers received for alfalfa hay was $115/ton, compared to $101/ton for other hay (USDA ERS, 2010c).

Alfalfa is grown for forage in almost every U.S. state. U.S. production of hay/haylage and seed harvested for the 2006 season is shown in Table 2-1. Haylage is alfalfa that is chopped at higher moisture content than hay, and stored in silos, bunkers or plastic bags to enable controlled fermentation to preserve the nutritional content. The major U.S. alfalfa producing regions include the Southwest, PNW, Inter-Mountain, Plains, North Central, and East-Central. The North-Central and the East-Central regions are the highest acreage hay and haylage regions in the U.S.; whereas, the Southwest and PNW regions produce the most seed in the U.S. (USDA NASS, 2010b).

Table 2-1 Alfalfa Forage and Seed Production by State
2006 National Agricultural Statistics Service Date

	State	Acres by State (1000s)		Hay and Haylage Harvested				
		Dry Hay 2006	Hay and Haylage 2006	Average Yield T/A	Forage Tons Harvested	Seed Production Acres	Average Yield (lbs/A)	Seed Lbs Harvested
Southwest	AZ	250	250	8.3	2,075	4	500	2,000,000
	CA	1,050	1,070	6.9	7,426	38	550	20,900,000
	NM	220	234	51	1,184	2	400	800,000
	Total	**1,520**	**1,554**		**10,685**	**44**		**23,700,000**
PNW	ID	1,180	1,230	4.5	5,523	28	700	19,600,000
	NV	270	270	5.1	1,377	5	600	3,000,000
	OR	430	430	4.4	1,892	5	650	3,250,000
	WA	440	455	4.9	2,239	15	750	11,250,000
	Total	**2,320**	**2,385**		**11,031**	**53**		**37,100,000**
Inter-	CO	780	780	3.8	2,964	0.6	200	390,000
Mountain	MT	1,550	1,550	2.1	3,255	5.5	200	3,025,000
	UT	560	560	4	2,240	2.2	200	1,320,000
	WY	500	500	2.8	1,400	7.5	400	4,125,000
	Total	**3,390**	**3,390**		**9,859**	**15.8**		**8,860,000**
Plains	KS	950	965	3.8	3,677	0.5	200	100,000
	NE	1,250	1,265	3.3	4,212	0.4	200	80,000
	OK	380	380	2.1	798	0.4	200	80,000
	TX	150	160	4.4	707	1	400	400,00
	Total	**2,730**	**2,770**		**9,394**	**2.3**		**660,000**
North	IA	1,180	1,230	4	4,908	0	0	0
Central	MN	1,350	1,500	3.6	5,460	0	0	0
	ND	1,450	1,450	1.2	1,740	0	0	0
	WI	1,650	2,400	3.9	9,336	0	0	0
	SD	1,800	1,820	1.6	2,930	7	250	1,750,000
	Total	**7,430**	**8,400**		**24,374**	**7**		**1,750,000**
East	CT	7	7	2.1	15	0	0	0
Central	DE	5	5	3.9	20	0	0	0
	IL	440	460	4.2	1,918	0	0	0
	IN	360	360	4.1	1,476	0	0	0
	ME	10	10	1.9	19	0	0	0
	MD	40	40	3.9	156	0	0	0
	MA	13	13	2.3	30	0	0	0
	MI	830	980	4	3,940	0	0	0
	MO	390	400	3	1,184	0	0	0
	NH	8	8	2.4	19	0	0	0
	NJ	25	25	2.5	63	0	0	0
	NY	370	610	3.3	2,019	0	0	0
	OH	470	550	4	2,195	0	0	0
	PA	500	660	3.8	2,515	0	0	0
	RI	1	1	3	3	0	0	0
	VT	45	90	3.6	322	0	0	0
	Total	**3,514**	**4,219**		**12,894**	**0**		**0**

Source: USDA APHIS, *2009, Table 3-20*

Cultural practices

Seeding and planting. The objectives of seedbed preparation are to manage crop residue (the leftover vegetative matter from the previous crop), minimize erosion, improve soil structure, and eliminate early season weeds. Alfalfa requires a good establishment for a long-lived productive

stand. Results from seed failure include poor seedbed preparation, seeding too deep or too shallow, low moisture availability, freezing, diseases, insects, damage from herbicides, and excess competition for light and nutrients from a companion crop or from weeds. Slight differences in seeding may be in the equipment used, such as, drills, broadcasting, or aerial broadcasting. Seeding time during the year varies from region to region. Northern areas will generally seed in spring to avoid major freezing damage of young seedling plants whereas all other areas will seed in the fall. Recommended seeding times are based on the previous crop, soil water availability throughout the year, and the time of year. The recommended soil preparations are similar in all regions unless no-till planting is used and no-till planting can be used in all regions (USDA APHIS, 2009, p. 84). No-till productions systems do not have any associated tillage where weed control is entirely through chemical means.

Fertilizing. The only differences in fertilizing among alfalfa growers occur in the composition of the fertilizer used because of the different soil types in different regions. All regions generally recommend good availability of phosphorus and potassium. Nitrogen fertilizer is generally not recommended unless considerable refuse from the previous crop exists (USDA APHIS, 2009, p. 84).

Harvesting. Alfalfa grown for forage can be used for grazing or harvested as greenchop, haylage/silage or hay. The only major difference for harvesting in different regions is the total number of harvests per year. The northern regions typically have up to two or three harvests per year due to shorter growing seasons. Southern regions can have six or more harvests per year. The major differences are in the adaptation of different varieties to the different climates of the U.S. and differing levels of various pests (weeds, disease, and insects) (USDA APHIS, 2009, p. 84).

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Crop rotations. Crop rotations can help maintain soil fertility, reduce soil erosion, avoid pathogen and pest buildup, adapt to weather changes, avoid allelopathic effects (effects to reduce the growth of one plant due to chemical releases by another) and increase profits.

Weeds can be a problem in alfalfa, but once alfalfa is established, it acts as a suppressor of weeds and is commonly used in rotations for weed reduction. Alfalfa is also used in crop rotations because it provides nitrogen to the soil, which decreases fertilizer inputs in other rotations. Rotating perennials, such as alfalfa, with annuals also helps control weeds and improves soil tilth. Using other crops to rotate with alfalfa is likewise advisable because mature alfalfa is autotoxic to seedling alfalfa. (USDA APHIS, 2009, p. 73 and 75).

2.2.2 Organic alfalfa hay production

Between 2000 and 2005, the number of acres in certified organic alfalfa hay production fluctuated slightly, but overall showed an increasing trend. The percentage of total alfalfa hay acres certified as organic per year was between 0.51 to 0.92 percent nationally during this time period (see Table 2-2). During 2005 (the most recent year for which certified organic alfalfa acres are reported), there were 204,380 acres in certified organic production, which was approximately 0.92 percent of the U.S. alfalfa dry hay total (USDA APHIS, 2009, p. 48).

Table 2-2 Organic Alfalfa Hay Harvested Acreage.

Acreage	2000	2001	2002	2003	2004	2005
Total	113,157	116,608	155,437	135,717	175,260	204,380
Share of Total U.S. Acreage	0.51%	0.49%	0.67%	0.58%	0.81%	0.92%

Source: USDA-ERS, 2005; USDA-NASS, 2007; USDA APHIS, 2009, p. 48

Organic alfalfa hay production is similarly distributed geographically to conventional hay. However, production of organic alfalfa hay is a more significant proportion of total alfalfa hay production in some States. In 2005, for example, more than 4 percent of all alfalfa hay acreage in Idaho was organic, compared to just 0.92 percent nationally. Organic alfalfa, like organic dairy, also seems to occur in pockets, with 72 percent of organic acreage located in just 6 States—Idaho, Wisconsin, Minnesota, North Dakota, South Dakota, and California. These 6 States account for about 41 percent of total U.S. alfalfa acreage (USDA APHIS, 2009, p. 48).

The increased price per ton of hay received by organic growers is partially offset by a reduction in forage quality (due to increased weeds in the hay) and an approximately 12.5 percent reduction of alfalfa yield per acre (Long et al., 2007). The 2005 national average yield per acre for all alfalfa hay production was 3.39 tons. Based on differences in organic and conventional alfalfa yield from Long et al. (2007), the total estimated U.S. organic hay production in 2005 was about 606,242 tons; the total U.S. production of alfalfa hay in 2005 was approximately 76,149,000 tons. The resulting eaverage organic alfalfa yield per acre, in 2005, was 2.97 tons. This estimate is approximate, however, and is only presented here for illustrative purposes (USDA APHIS, 2009, p. 48).

2.2.3 Seed production

Maintaining seed purity, identity and quality

The Federal Seed Act and its implementing regulations[38] establish basic standards for certification of seed, which are carried out by state seed certifying agencies. A state seed certifying agency is created by state law, has authority to certify seed, and has standards and procedures approved by USDA "to assure the genetic purity and identity of the seed certified." Seed certifying agencies' standards and procedures must meet or exceed those specified in the

[38] 7 C.F.R. §201.

USDA regulations.[39] Federal law also allows for international seed certification. Through the certification process, the certifying agency "gives official recognition to seeds produced of a cultivar or named variety under a limited generation system which ensures genetic purity, identity, and a given minimum level of quality" (USDA, 2009a). In the case of alfalfa, State Crop Improvement Associations (or sometimes Seed Grower Associations) provide certifications that seed production followed minimum standards, such as isolation between different alfalfa varieties, absence of prohibited noxious weeds in the field, inspection of conditioning (separation) facilities, maintaining traceability of seed lots, and seed testing (USDA APHIS, 2009).

The most common levels of certification that would normally be available for consumer purchase would be "registered seed" or "certified seed." Breeder seed is controlled by the seed developer and is the source for the production of the other classes of certified seed, and foundation seed is normally used to establish new production fields (USDA, 2009a and 7 C.F.R. § 201.2). Standards are highest for Breeder/Foundation seed, next highest for Registered; while "Certified" has the least stringent requirements of the certified categories. In all cases, the party seeking the certification is responsible for ensuring the requirements are met.

Certified seed must have a label indicating, among other things, the percent of pure seed, inert matter, other crop, and weed seed. Seed purity standards vary between states but remain high, particularly for foundation seed stock. At least 99 percent of each seed harvest must contain the pure seed variety (i.e. < 1 percent genetic off-types), and there are strict limits on the allowable amounts of other crops, weeds and inert matter. After seed crops have been evaluated by seed labs, they are tagged with seed labels in accordance with law. The Association of Official Seed Certifying Agencies (AOSCA) requires that a representative sample from each submitted crop undergo multiple tests at a seed lab. All types of seed crops must be accurately labeled. The Foundation and Certified seeds are identified by a special tag that includes variety, kind, origin, net weight, percent pure seed, percent other materials, amount of noxious seed and weeds, and identification of the seed lab performing the analysis (USDA APHIS, 2009).

California, the leading producer of alfalfa seed, provides an example of typical rules for field eligibility (past use and spatial isolation) and seed purity standards. These rules are followed by most states. For cultivating Foundation seed (seed of the highest purity), alfalfa must not have grown on the land in the previous four years. For Certified seed, alfalfa must not have been grown on the land in the previous one to two years. These past use requirements may vary

[39] 7 U.S.C. §1551(a)(25); 7 C.F.R. §201.67.

depending on the intervening crops. The boundaries of the field must be clearly set and all noxious weeds and volunteer plants must be eradicated before planting. Foundation seed fields must be isolated from alfalfa of different varieties by 900 feet (ft). Certified fields must be isolated by 165 ft However, a "10 percent rule" provides some flexibility for Certified fields. Under this rule, if 10 percent or less of the Certified field is in the 165 foot isolation zone, then the entire field is considered Certified. However, if more than 10 percent is in the isolation zone, then that part of the field must be separated and not harvested as Certified seed (USDA APHIS, 2009).

Summary of practices for alfalfa seed production

Unlike alfalfa hay production, alfalfa seed production is largely concentrated both geographically and in the number of producers. Seed production occurs primarily in niche areas of the western U.S. on approximately 100 to 120 thousand acres under intensive management and irrigated field conditions (see Figure 1-1). It requires a long growing season with a very warm temperature, very low humidity during seed ripening, and specialized equipment. Most professional seed producers use cultured bees and specialized equipment associated with bee culture (USDA APHIS, 2009, p. 68).

Based on the 2007 Census of Agriculture, the top three seed producing states, accounting for over 60 percent of production, were California with 31 percent of produced seed, Washington with 17 percent, and Idaho with 15 percent. The remaining seed production was highly concentrated in the western states of Nevada, Oregon, Wyoming, Montana, and Utah (USDA APHIS, 2009).

As shown in Table 3-9 of the draft EIS (included as Figure 1-1 of this ER), within the seed producing states seed production is localized to certain counties. In the most recent USDA-NASS Census of Agriculture (2007), during 2002 and 2007, 1,234 and 806 farmers grew alfalfa seed on 110.6 and 120 thousand acres, respectively. This is a small number of growers in comparison to those growing alfalfa for forage (i.e., 344,000 and 290,000 alfalfa hay growers in 2002 and 2007, respectively). During 2007, 90 percent of the U.S. seed crop tonnage was grown by 304 seed growers operating farms with at least 100 acres of alfalfa seed (USDA-NASS, 2009). Therefore, most of the alfalfa seed production is managed by a relatively small number of large professional seed producers. Nearly all large growers have at least one proprietary seed production contract with one of the four national alfalfa seed production companies (USDA APHIS, 2009, p. 68-69).

Cultural practices used to produce seed are distinct from those used to produce forage. Professional seed growers usually grow seed under terms of a two or three year term seed company contract, by variety name. The contracting seed company supplies the stock seed (e.g., foundation seed) to the seed producer and the genetic source variety of the seed is documented. In contrast, seed companies purchasing or growing "common seed" or "catch crop" seed typically use lower management and inputs, the genetic identity of the stock seed is often unspecified/unknown and the resultant product quality is highly variable and cannot be certified as to cultivar or variety identity (USDA APHIS, 2009, p. 69).

Typically, seed fields are planted in the fall and clipped back in late spring so that bloom within the field is uniform, synchronous and optimally timed for the warm dry season and optimal pollinator activity. Weed and in-crop volunteer controls (herbicides and cultivation) are applied mainly prior to the start of pollination or after seed harvest. Flowering begins in approximately mid-June. Insecticides (primarily for *Lygus* control) and other pesticides are applied prior to bee release to avoid insecticide damage to the bees. At approximately 50 percent flower (early to mid-July), cultured bees are gradually moved into the seed field for pollination with their domicile or hive for local shelter. The field is actively pollinated for approximately one month, allowed to ripen seed for approximately 4 weeks more, and then, chemically desiccated or swathed several days prior to combining the seed. At the end of the pollination period and just prior to desiccation, the pollinating generation of bees is either at the end of their lifecycle (i.e., leafcutter or alkali bees), or are transported by the honeybee keeper to a different location to forage on fall-flowering plant species. Seed is harvested in mid August to late September depending on geography. In long-growing season regions, the cool-season alfalfa forage growth between seed crops is sometimes mechanically harvested or grazed (USDA APHIS, 2009, p. 69).

Stands of alfalfa grown for seed production only are usually maintained for an average of three production seasons. The length of the seed stand is generally predetermined by the seed production contracts and AOSCA variety certification standards. In contrast to forage stands, most alfalfa seed planted for seed production purposes is planted at a low density in widely spaced rows and not cut monthly. Consequently, weeds in the seed fields have more open area and time to proliferate and compete with the alfalfa. Therefore, weeds, insects, and pests are intensively managed in seed production systems. Weed seeds and weed debris in grower seed lots directly reduce the purity and yield of alfalfa seed and drive up growers' costs to remove them (USDA APHIS, 2009, p. 69-70).

RRA seed production since 2005

In 2006-2007, RRA seed was produced in the U.S. on a widespread basis for the first time since deregulation in 2005. This presented an opportunity for FGI to implement an internal seed quality program to monitor the efficacy of the FGI Best Practices for RR Stewardship during Seed Production ("FGI Best Practices"). Conventional alfalfa seed lots grown and/or processed in proximity to RR seed in 2006 and 2007 were tested for the adventitious presence (AP) of the RR trait. The data showed that the AP of the RR trait in FGI conventional seed lots occurred infrequently and, in all cases if detected, was at a very low level—0.004 to 0.180 percent. This was well within the FGI's goal of <0.5 percent AP. This large-scale commercial validation of FGI Best Practices supports research-based isolation standards and demonstrates the effective implementation of quality control programs at both the grower and processor level. FGI believes that this, and more recent industry reviews together demonstrate that reasonable tools are available and are being used by seed producers to allow successful coexistence of diverse alfalfa seed market sectors and preserve conventional seed and hay market choices (USDA APHIS, 2009). In late 2007, following the Court's Decision, the FGI Best Practices were extensively reviewed by the Steering Committee of the National Alfalfa & Forage Alliance Peaceful Coexistence Workshop (October 10, 2007). The steering committee was composed of a broad array of alfalfa industry stakeholders. In January, 2008, NAFA's Board of Directors and all genetic suppliers of NAFA adopted the NAFA BMP (Appendix C) as requirements for RRA seed producers. A third-party panel of State Seed Certification Agencies has reviewed 2008 and 2009 conventional alfalfa seed crop year data and has stated that the NAFA BMP appear to be working to achieve coexistence, i.e., conventional and RRA varieties have been produced successfully during the period following widespread cultivation of RRA.

All alfalfa seed production since 2005

The latest information of total alfalfa seed production is from the 2007 Census of Agriculture, when 121,467 acres of alfalfa seed were harvested producing approximately 62 million pounds of seeds at an average productivity of approximately 510 lbs/acre.

Alfalfa seed acreage and production increased between 2002 and 2007, reversing the trend of decreases in alfalfa seed production over the preceding few years. Economic, social and competitive challenges face both U.S. alfalfa seed and forage growers. These challenges include: changes in global seed demand and production, economics, environmental constraints, regulatory issues, and insect control and weeds. The presence of weeds can have a greater impact on costs in alfalfa seed production than alfalfa forage production. Post-harvest

separation of weed seed from the alfalfa seed is costly; therefore, the control of weeds in the field is a more desirable method of seed quality control. No primary or secondary noxious weeds are allowed for certified seed (USDA APHIS, 2009, p. 43-44).

Seed availability

All four of the major U.S. seed genetic suppliers and seed production companies (FGI, Pioneer Hi-Bred, Dairyland Seeds and Cal/West Seeds) sell conventional and/or organic seed products. Prior to the federal court injunction, these varieties were sold alongside of one or more RRA varieties. RRA was sold by more than 20 seed brands all of which continued to offer conventional cultivar products (USDA APHIS, 2009).

During the 2005-2007 period of deregulation of RRA, approximately 200,000 and 18,000 acres of RRA hay and seed, respectively, were grown with no substantiated disruption of the market for conventional alfalfa hay or seed (USDAS APHIS, 2009; McCaslin, 2007).

Organically certified and conventionally grown seed lots are routinely marketed to U.S. organic forage producers for the establishment of organic alfalfa forage fields. Although a small amount of organic alfalfa seeds used in the U.S. are purchased from U.S. seed distributors, little or none of the organic alfalfa seeds appear to have been originally grown in the U.S. (McCaslin, 2007). There is little information available to indicate if there are any certified organic alfalfa seed producers in the U.S. (USDA APHIS, 2009). Organic alfalfa seed sold in the U.S. by U.S. seed companies is therefore most likely to have been wholly or largely imported from organic producers in Canada or elsewhere, where insect pests in alfalfa seed production are less catastrophic and base production costs for seed are much lower (McCaslin, 2007).

2.3 GENE FLOW

This section provides background information on gene flow, which is relevant to the impacts analysis provided in Section 3 of this ER.

Gene flow has been defined as the "incorporation of genes into the gene pool of one population from one or more populations" (Futuyma, 1998). Gene flow is a basic biological process in plant evolution and in plant breeding, and in itself does not pose a risk (Bartsch et al., 2003; Ellstrand, 2006, p. 116).

There are several factors that influence the probability of gene flow between alfalfa fields. The following is a list of factors adapted from Putnam, 2006 (USDA APHIS, 2009, p. 100):

- Probability of synchronous flowering (e.g., the percentage of days where several plants flower simultaneously);
- Relative availability and abundance of pollen from various sources (e.g., the percentage of bloom during each day of synchronous flowering);
- Presence of pollinators and pollinator types
- Pollinator activity on days of synchronous flowering and placement of bee hives (e.g., influenced by timed bee release and weather);
- Distance between fields (alfalfa populations);
- Probability of seed maturation; and
- Probability of seed germination.

2.3.1 Hybridization

In plant biology, when gene flow occurs between individuals from genetically distinct populations and a new plant is formed, the new plant is called a hybrid (Ellstrand, 2003, p. 10). Hybridization is usually thought of as the breeding of closely related species or subspecies resulting in the creation of a plant that has characteristics different from either parent. Usually this occurs through deliberate human efforts; however, it can also occur indirectly from human intervention, or in nature. For example, when plants are moved to a new environment (with or without human intervention), they may hybridize with plants of a closely related species or subspecies in that new location.

For natural hybridization to occur between two distinct populations, the plants from the two populations must flower at the same time, they must be close enough so that the pollen can be carried from the male parent to the female parent, fertilization must occur, and the resulting embryo must be able to develop into a viable seed that can germinate and form a new plant (Ellstrand, 2003, pp. 11-13).

Characteristics that favor natural hybridization between two populations when the above requirements are met include (Mallory-Smith and Zapiola, 2008, p. 429):

- Presence of feral populations (domestic populations gone wild) and uncontrolled volunteers
- Presence of a high number of highly compatible relatives
- Self-incompatibility

- Large pollen source
- Large amounts of pollen produced
- Lightweight pollen
- Large insect populations (insect pollinated)
- Long pollen viability

Feral populations are discussed in Section 2.6. **Volunteers** are plants from a previous crop that are found in a later crop and are also discussed in Section 2.6.

There are **no sexually compatible** wild relatives of alfalfa present in the U.S. (Mallory-Smith and Zapiola, 2008; Van Deynze et al., 2008, p. 7). Therefore, movement of the CP4 EPSPS gene found in RRA varieties can only occur within or among cultivated or feral alfalfa populations (USDA APHIS, 2009, p. 94).

Alfalfa (*Medicago sativa* L.) is predominantly **self-incompatible**; that is, fertilization does not occur between the male and female parts on the same plant. Self-incompatible plants must be cross-pollinated (also known as "out-crossed") to form viable seed: that is, for fertilization to occur, the female part of the flower (the stigma) must successfully receive pollen from the male part of a second plant (the anther). The majority of cross-pollination in alfalfa is effected by bees visiting plants growing in very close proximity (i.e., within four meters) (St. Amand et al., 2000).

As discussed in Section 2.1.2, alfalfa is exclusively **insect-pollinated**, and, in seed production areas, farmers must stock bees to ensure economic levels of seed production.

Gene flow via seed mixtures

Nearly all alfalfa forage producers purchase seeds for planting, largely because grower-produced grower-saved-seed is only possible in the niche seed-growing geographies. Commercially produced seed is generally produced under a contract from a seed company: the foundation stock seed is provided to the contract grower by the seed company and seed lots are harvested, transported and conditioned by variety name and lot code. Such contracts and the typical use of official seed certification schemes maintain field and seed lot segregation, identity and varietal purity. Seed certification standards set limits on the percentage of other variety off-types that are allowed. Therefore, seed growers and seed producers are aware of the importance of routine cleaning of field equipment, seed transportation containers and seed processing equipment as means to mitigate off-types and weed seed presence to very low

levels. Regardless of stringent management, commercial agricultural seeds are not and cannot be 100 percent pure. Therefore, it is widely recognized that some seed admixtures may still inadvertently occur, and that, in all but exceptional cases they are likely to pose no safety, economic or regulatory issues.

2.3.2 Seed-to-seed gene flow studies

FGI performed gene flow studies in Idaho from 2000 to 2002 using leafcutter bees for pollination, however, the presence of feral and native bees were also noted. These studies showed a mean gene flow of 1.39 percent at 500 ft and 0.0000 percent at ¾ of a mile (Fitzpatrick et al., 2002). Table 2-3 and Figure 2-1 below summarize the findings of these field studies.

Table 2-3. Summary of FGI Idaho Gene Flow Studies (Fitzpatrick et al., 2002)

Isolation distance	Year 2000	Year 2001 [a]	Year 2002 [a,b]	2000-2002 Overall Mean Observed gene flow (99.9% C.I. upper bound)
0 ft (Source Plot)	*Source* (1.0 A)	*Source* (1.6 A)	*Source* (1 A)	
500 ft	Reps 1-4: 0.03 A, N [c]	-	-	1.39% (1.72%)
900 ft	-	Rep 1: 0.7 A, N. Rep 2: 1.6 A, N.E.	-	0.28% (0.34%)
1000 ft	Reps 1-4: 0.03 A, N [c]	-	-	0.32% (0.45%)
1500 ft	Reps 1-4: 0.03 A, N [c]	Rep 1: 1.6 A, W. Rep 2: 1.6 A, N.W.	Rep 1: 1 A, S.W. Rep 2: 1 A, S.E.	0.08% (0.13%)
2000 ft	Rep 1: 2.0 A, N.W. [c]	-	-	0.00% (0.05%)
2640 ft (1/2 mi)	-	-	Rep 1: 1 A, S.W. Rep 2: 1 A., S.E.	0.003% (0.02%)
3960 ft (3/4 mi)	-	-	Rep 1: 1 A, S.W. Rep 2: 1 A, S.E.	0.0000% (0.01%)
5280 ft (1 mi)	-	-	Rep 1: 1 A, N.W. Rep 2: 1 A, S.E.	0.0000% (0.01%)
Mean no. seed tested per trap distance	14,750	41,250	60,000	

Notes: Isolation distance between trap and source, number of replicates per distance, replicate plot size (acres), trap plot cardinal direction from source and, interplot land cover a,b,c, the mean observed gene flow and the upper bound of true gene flow (i.e., the 99.9 percent confidence interval upper limit) are given. Interplot land cover:a various crop species typical for the area (e.g., onions, corn, wheat, etc.); b roadways, or c fallow. "-" indicates distance not tested.

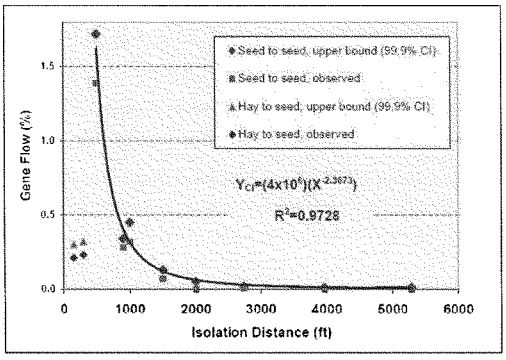


Figure 2-1 – Gene Flow

UC—Davis, Monsanto/FGI performed a gene flow study during the 2003 growing season using honey bees. The pollen-mediated gene flow at isolation distances of 900 ft, 5,000 ft, and 2.53 miles were 1.49 percent, 0.2 percent, and ≤0.06 percent, respectively (Teuber et al., 2007).

A mixed honey bee and leafcutter bee gene flow study was performed in the San Joaquin Valley of California in 2006 and 2007 (Teuber et al., 2007; Van Deynze et al., 2008). Summary data from those studies are presented in the Table 2-4 below.

Table 2-4 Seed to Seed Gene Flow (Teuber et al., 2007)

Distance	Gene Flow (% adventitious presence)
165 ft.	2.3
900 ft.	0.9
4,000 ft.	0.6
1 mile	0.2
3 miles	0.03
5 miles	Not detected

FGI conducted a gene flow study subsequent to the 2006 growing season which validated the FGI Best Practices (FGI, 2007). The observed gene flow ranged from 0.09 percent at an isolation distance of one mile to 0.01 percent at an isolation distance of three miles. At distances of 5 miles or greater, the gene flow was not detected.

To summarize, data collected under actual seed production conditions found gene flow ranging from 0.00 to 0.18 percent when FGI Best Practices were used. This is well below the FGI Company's domestic market goal of less than 0.5 percent adventitious presence. As required by the NAFA BMP (2008a), a third-party review panel has annually conducted a review of conventional seed crop gene flow data. In each of the two annual reviews, the panel has validated that NAFA BMP are working on a commercial scale to enable coexistence among conventional and RRA seed producers (NAFA, 2009; Fitzpatrick and Lowry, 2010).

2.3.3 Gene flow potential

This ER addresses potential gene flow pathways as follows:

- Potential for gene flow from RRA forage crops to conventional and organic forage crops (Section 3.3)
- Potential for gene flow from RRA forage crops to native alfalfa (Section 3.4)
- Potential for gene flow due to feral alfalfa populations (Section 3.5)
- Potential for gene flow from RRA forage crops to rangeland alfalfa (Section 3.6)
- Potential for gene flow from RRA forage crops to conventional or organic alfalfa seed production areas (Section 3.7)
- Potential for gene flow from RRA to any of the above receptors, in alfalfa seed production (Section 3.8)

2.4 ALFALFA WEED MANAGEMENT

2.4.1 Weed characteristics and concerns

While a weed can be defined as any unwanted plant, problem weeds are those that are competitive and persistent. Healthy, productive stands of alfalfa require attention to manage pests (including weeds), fertilizer inputs, irrigation (if applicable), and harvest timing. Weeds can be a problem in alfalfa particularly at establishment of a new stand and after the stand has started to thin toward the end of its life. Once a dense stand of alfalfa has been established, the competition of the alfalfa plants with weeds and the fact that alfalfa is cut at regular intervals during the production season act as suppressors of weeds. Weed control at establishment is a particularly important time since good weed control at this time leads to the establishment of a dense, healthy stand for the life of the crop.

Several years after sowing alfalfa when plants weaken and stands become thin weeds become more competitive with alfalfa and can contribute to a significant decline in alfalfa yield and forage value. Certain weed species found in alfalfa stands are particularly difficult to control, are poisonous to livestock, negatively affect palatably or livestock performance, impart off flavors to milk products, and may be noxious regulated species (USDA APHIS, 2009, p. 73).

Competition for light, water and nutrients. A grower tries to capture the plant resources on his land - primarily light, water, and nutrients - for his crop; however, competitive weeds often secure some of these resources for their growth, at the expense of the crop. Some common characteristics of competitive weeds are rapid seedling establishment, high growth rates, prolific root systems and large leaf areas.

Weed persistence. Persistent weeds are able to survive year after year on a given piece of ground, in spite of a farmer's efforts to control them. Some plants are both competitive and persistent through the production of large numbers of seeds. The bushy wild proso millet, for example, shatters upon contact when mature, and can produce 400 to 12,000 seeds per square foot. While high reproductive rates also contribute to a weed's persistence, seed dormancy is also an important trait in persistence. Cultivated soils typically contain thousands of seeds per square meter, waiting for the opportunity to germinate. Some seeds, for example, velvetleaf, can remain viable in the soil for up to 50 years. Many perennial weed species have the ability to reproduce from root fragments. Canada thistle, for example, has a deep, spreading root system that can continue to send up shoots after the surface plant has been removed multiple times. Some weeds have the ability to alter their characteristic in response to stress; for example, some weeds respond to drought by flowering and going to seed early (Tranel, 2003; McDonald et al., 2003, pp. 9-12).

Weeds are controlled in conventional alfalfa and RRA with chemicals (herbicides), cultural methods (rotation, mowing, companion crops, monitoring), and mechanical methods (tillage). The cultural and mechanical methods are permitted for organic farmers. RRA systems allow for the use of one additional herbicide, glyphosate.

2.4.2 Problem weeds in alfalfa production

The following weeds have been identified as problem weeds in alfalfa that prevent production of maximum yields: Barnyardgrass, Bermudagrass, Bluegrass (annual), Bromes, Buckhorn plantain, Bulbous bluegrass, Burning nettle, Canarygrass, Chesseweed, Chickweed (common), Coastal fiddleneck, Cupgrass, Dandelion (common), Dodder, Filarees, Field bindweed,

Flixweed, Foxtail (green), Foxtail (yellow), Foxtail barley, Goosegrass, Groudsel (common), Hare barley, Johnsongrass, Junglerice, Knotweed, Lambsquarter (common), London rocket, Miner's lettuce, Mustards, Nettleleaf, Nightshade, Nutsedges, Palmer Amaranth, Pepperweeds, Prickly lettuce, Quackgrass, Redmaids, Russian thistle, Ryegrass, Shepardspurse, Sowthistle, tinkgrass, Wild oats, Wild Radish, Witchgrass, and Yellow starthistle (UC IPM, 2006) . These weeds are summarized in Table 2-5. Most of these weeds, and others, are present throughout all the alfalfa growing regions. Certain weeds are classified as annual, biennial or perennial. An annual or biennial is a plant that completes its life cycle to produce seed in one or two years (or less), respectively. Perennials are plants that live for more than two years. They may reproduce by seeds, rhizomes (underground creeping stems) or other underground parts. Weeds are further classified as broadleaf (dicots) or grasses (monocots).

Table 2-5 Weeds in Alfalfa

Common Name	Scientific Name and Synonyms	GR Biotype Reported in U.S.	Types	Season	East Central	North Central	Southeast	Winter Hardy Inter-Mountain	Great Plains	PNW	Moderate Inter-Mountain	Southwest
Barnyard grass	*Echinochloa crus-galli*, cockspur grass, Japanese millet watergrass cockspur watergrass	NA	Grass	SA	X	X			X	X	X	X
Bermudagrass	*Cynodon spp.*	NA	Grass	P			X		X			X
Bluegrass (annual)	*Poa annua* walkgrass, annual bluegrass	NA	Grass	WA			X		X			X
Bromes	Bromus spp.	NA	Grass	WA								X
Buckhorn plantain[1]	***Plantago lanceolata***	**No**	**Broadleaf**	**P**					**X**		**X**	
Bulbous bluegrass	*Poa bulbosa*	NA	Grass	P							X	
Burning nettle	*Urtica dioic* California nettle slender nettle stinging nettle tall nettle	NA	Broadleaf	A								X
Canarygrass	*Phalaris arundinacea* canary grass reed canarygrass *Phalaris canariensis* canary grass *Phalaris minor* canarygrass littleseed canarygrass	NA	Grass	WA								X
Chesseweed	*Malva neglecta* buttonweed	NA	Broadleaf	WA-P							X	X

Common Name	Scientific Name and Synonyms	GR Biotype Reported in U.S.	Types	Season	East Central	North Central	Southeast	Winter Hardy Inter-Mountain	Great Plains	PNW	Moderate Inter-Mountain	Southwest
	cheeseplant little mallow common mallow											
Chickweed (common)	*Stellaria media*	NA	Broadleaf	WA	X	X	X		X	X		
Coastal fiddleneck	*Amsinckia menziesii* var. *intermedia* coast buckthorn coast fiddleneck common fiddleneck fiddleneck	NA	Broadleaf	WA							X	
Cupgrass	*Eriochloa gracilis* southwestern cubgrass tapertip cupgrass *Eriochloa contracta* prairie cupgrass *Eriochloa villosa* wooly cupgrass	NA	Grass	SA					X			X
Dandelion (common)	*Taraxacum officinale* blowball common dandelion faceclock	NA	Broadleaf	P	X	X		X	X		X	
Dodder	*Cuscuta* 50 common names for the species in the genus	NA	Broadleaf	SA					X	X	X	X
Filarees	*Erodium spp.*	NA	Broadleaf	WA	X	X	X	X	X	X	X	X
Field bindweed	*Convolvulus arvensis* creeping jenny European bindweed morningglory perennial morningglory Smallflowered morningglory	NA	Broadleaf	P	X			X				
Flixweed	*Descurainia sophia* flixweed pinnate tansymustard	NA	Broadleaf	WA				X	X		X	
Foxtail (green)	*Setaria viridis* bottle grass green bristlegrass green foxtail green millet pigeongrass wild millet	NA	Grass	SA	X	X	X	X	X	X	X	
Foxtail (yellow)	*Setaria glauca* pearl millet pigeongrass	NA	Grass	SA	X	X	X	X	X	X		

Common Name	Scientific Name and Synonyms	GR Biotype Reported in U.S.	Types	Season	East Central	North Central	Southeast	Winter Hardy Inter-Mountain	Great Plains	PNW	Moderate Inter-Mountain	Southwest
	wild millet yellow bristlegrass yellow foxtail											
Foxtail barley	*Hordeum jubatum*	NA	Grass	P				X			X	
Goosegrass[1]	***Eleusine indica*** **crowsfoot grass** **Indian goosegrass** **manienie alii'i** **silver crabgrass** **wiregrass**	**No**	**Grass**	**SA**			**X**		**X**			
Groundsel (common)	*Senecio vulgaris* ragwort old-man-in-the-Spring	NA	Dicot	WA								X
Hare barley	*Hordeum leporinum* hare barley leporinum barley wild barley	NA	Dicot	WA				X			X	X
Johnsongrass[1]	***Sorghum halepense*** **aleppo milletgrass** **herbe de cuba** **sorgho d' Alep** **sorgo de alepo** **zacate johnson**	**Yes (1) State**	**Grass**	**P**			**X**		**X**			
Junglerice[1]	***Echinochloa colona*** **Junglerice** **watergrass**	**No**	**Grass**	**SA**								**X**
Knotweed	*Polygonum arenastrum* common knotweed doorweed matweed ovalleaf knotweed prostrate knotweed	NA	Broadleaf	SA						X		X
Lambsquarter (common)	*Chenopodium album* Lambsquarters White goosefoot	Yes	Broadleaf	SA	X	X	X	X	X	X	X	X
London rocket	*Sisymbrium irio*	NA	Grass	WA								X
Miner's lettuce	*Claytonia perfoliata*	NA	Dicot	WA-P								X
Mustards	*Brassica* spp.	NA	Broadleaf	WA			X	X				
Mustards	*Brassica* spp.	NA	Broadleaf	SA			X					
Nettleleaf	*Chenopodium murale*	NA	Broadleaf	SA								X
Nightshade	*Solanum sarrachoides* Hairy nightshade	NA	Broadleaf	SA			X			X		

Common Name	Scientific Name and Synonyms	GR Biotype Reported in U.S.	Types	Season	East Central	North Central	Southeast	Winter Hardy Inter-Mountain	Great Plains	PNW	Moderate Inter-Mountain	Southwest
Nutsedges	Hoe nightshade Cyperus esculentus yellow nutgrass yellow nutsedge *Cyprus rotundus* chaguan Humatag cocograss kili'o'opu nutgrass pakopako purple nutsedge	NA	Grass	P								X
Palmer Amaranth[1]	***Amaranthus palmeri*** **carelessweed (type of pigweed)**	**Yes (8) States**	**Broadleaf**	**SA**					**X**			
Pepperweeds	*Lepidium densiflorum* Common pepperweed Greenflower pepperweed peppergrass	NA	Broadleaf	WA					X		X	
Prickly lettuce	*Lactuca serriola* China lettuce wild lettuce	NA	Broadleaf	WA					X	X	X	
Quackgrass	*Elytrigia repens* couchgrass quackgrass quickgrass quitch scotch twitch *Elymus repens* couchgrass dog grass	NA	Grass	P	X	X					X	X
Redmaids	*Calandrinia ciliate*	NA	Broadleaf	WA						X		X
Russian thistle	*Salsola kali* tumbleweed *Salsola iberica* prickly Russian thistle tumbleweed tumbling thistle	NA	Broadleaf	SA		X			X	X	X	
Ryegrass[1]	***Lolium multiforum*** **Italian ryegrass** **annual ryegrass**	**Yes (3) States**	**Grass**	**WA**			**X**				**X**	
Shepardspurse	*Capsella bursapastoris* Shephardspurse	NA	Broadleaf	WA	X	X	X	X	X	X	X	X
Sowthistle	*Sonchus* spp. (5 species)	NA	Broadleaf	P						X		
Stinkgrass	*Eragrostis cilianensis* candy grass lovegrass strongscented	NA	Grass	SA							X	

Common Name	Scientific Name and Synonyms	GR Biotype Reported in U.S.	Types	Season	East Central	North Central	Southeast	Winter Hardy Inter-Mountain	Great Plains	PNW	Moderate Inter-Mountain	Southwest
Wild oats	lovegrass *Avena fatua* flaxgrass oatgrass wheat oats	NA	Grass	SA-WA		X				X	X	X
Wild Radish	*Raphanus raphanistrum*	NA	Broadleaf	SA	X	X	X					
Witchgrass	*Panicum capillare* panicgrass ticklegrass tumble panic tumbleweed grass witches hair	NA	Grass	SA	X						X	
Yellow starthistle	*Cantaurea solstitialis*	NA	Dicot	WA				X			X	

1 – Glyphosate resistant weed
Note: Refer to Table G-8 in the draft EIS for Glyphosate resistant weed infestations by state
Source: (UC IPM. 2006), (USDA APHIS, 2009, Tables G-3 and G-7), and (USDA, 2010b)

2.4.3 Use of herbicides to control weeds

Herbicides are used at three different phases in conventional alfalfa farming, which include stand establishment (to prepare the ground), established stands (to control weeds), and during stand removal (to kill alfalfa). The 17 EPA-registered herbicides that are used for stand removal or to control volunteer alfalfa include:

Herbicide	Mode of Action
2,4-DB (Butyrac, Butoxone)	- Synthetic Auxin; Growth regulator
Benfluralin (Balan)	- Dinitroanalines; Microtubule assembly inhibition
Bromoxynil (Buctril) -	- Nitriles; Photosystem II inhibitors
Clethodim (Prism, Select)	- Acetyl-CoA carboxylase (ACCase) inhibitors
Diuron (Karmex, Direx)	- Ureas, Amides; Photosystem II inihitors
EPTC (Eptam)	- Thiocarbamates; Seed growth inhibitors (shoot)
Hexazinone (Velpar)	- Photosystem II inhibitors
Imazamox (Raptor)	- Acetolactate synthase (ALS) inhibitors
Imazethapyr (Pursuit)	- ALS inhibitors
Metribuzin (Sencor)	- Photosystem II Inhibitors
Norfluzaon (Solicam)	- Carotenoid biosynthesis inhibitors
Paraquat (Gramoxone Inteon)	- Bipyridiliams; Cell membrane disruptor

Pronamide (Kerb)	- Dinitroanilines; Microtubule assembly inhibition
Sethoxydim (Poast)	- ACCase Inibitors
Terbacil (Sinbar)	- Photosytem II Inhibitors
Trifluralin (Treflan/TR-10)	- Dinitroanilines; Microtubule assembly inhibition

Source: (USDA APHIS, 2009, Table G-1) and (Heap, 2010)

Table 2-6 summarizes the effectiveness of the herbicides on broadleaf weeds in seedling alfalfa, Table 2-7 summarizes the effectiveness of the herbicides on grass weeds in seedling alfalfa, and Table 2-8 summarizes the effectiveness of herbicide combination control on weeds in seeding alfalfa.

Alfalfa stands are usually thinning and vulnerable to weeds after 2 to 8 years. Alfalfa stands are typically removed by killing the alfalfa by either tillage, herbicide application, or both. RRA cannot be removed using glyphosate; therefore, just like conventional alfalfa, RRA can be removed using tillage and/or labeled, non-glyphosate herbicides.

Table 2-6 Susceptibility of Broadleaf Weeds in Seedling Alfalfa to Herbicide Control

	POSTEMERGENT																	
BROADLEAF WEEDS	**24DB[-1]**	**24DB[-3]**	**24DB[-4]**	**BRO[1]**	**BRO[2]**	**CLE[1]**	**CLE[2]**	**GYL[+]**	**HEX**	**IMA[1]**	**IMA[2]**	**IMZ[1]**	**IMZ[2]**	**PAR[-1]**	**PAR[-2]**	**PRO**	**SET[1]**	**SET[2]**
burclover	N	N	N	N	N	N	N	P	P	N	N	N	N	N	N	N	N	N
buttercup	N	N	N	N	N	N	N	-	-	C	C	P	C	P	C	-	N	N
celery, wild	N	N	N	N	N	N	N	C	P	N	N	N	N	N	P	-	N	N
chickweed	N	N	N	N	N	N	N	C	P	C	C	C	C	P	C	N	N	N
cocklebur	C	C	C	C	C	N	N	C	C	C	C	C	C	N	P	N	N	N
dock, curly (seeding)	P	C	C	N	N	N	N	C	N	N	P	N	N	N	N	P	N	N
doverfoot	N	N	P	N	N	N	N	C	-	C	C	C	C	P	C	N	N	N
fiddleneck	N	N	N	C	C	N	N	P	P	N	P	N	P	N	P	N	N	N
fillarees	N	N	N	N	N	N	N	P	P	P	C	P	C	N	P	N	N	N
groundsel, common	N	P	C	P	C	N	N	C	C	N	N	N	N	N	P	N	N	N
henbit	N	N	N	N	N	N	N	C	N	N	P	P	C	N	N	C	N	N
jimsonweed	P	C	C	C	C	N	N	C	-	C	C	C	C	C	C	-	N	N
knotweed (seedling)	N	P	C	P	P	N	N	C	C	P	C	P	C	N	N	C	N	N
lambsquarters	C	C	C	C	C	N	N	C	C	N	N	P	C	P	C	C	N	N
lettuce, miners	N	N	N	N	N	N	N	C	P	C	C	P	C	P	C	C	N	N
lettuce, prickly	P	C	C	P	C	N	N	C	N	N	N	N	C	P	C	C	N	N
mallow, little (cheeseweed)	N	N	N	N	N	N	N	P	N	P	C	P	C	N	N	N	N	N
milkthistle	N	N	P	N	P	N	N	C	-	N	N	N	N	P	P	N	N	N
mustard, black	N	P	C	C	C	N	N	C	P	C	C	C	C	N	P	N	N	N
nettle, burning	N	N	P	N	N	N	N	P	N	P	C	P	C	N	N	N	N	N
nightshade, hairy	P	C	C	C	C	N	N	C	C	C	C	C	C	-	C	C	N	N
oxtongue, bristly	-	P	P	P	C	N	N	-	-	N	P	-	-	-	-	-	N	N
pineappleweed	N	N	N	N	P	N	N	C	P	N	N	N	N	P	C	N	N	N
pigweed, redroot	C	C	C	N	P	N	N	C	C	C	C	C	C	N	N	C	N	N
radish, wild	N	P	C	N	P	N	N	C	P	P	C	P	C	N	P	N	N	N
rockpurslane, desert	N	N	N	N	N	N	N	C	N	C	C	N	N	P	C	P	N	N
rocket, London	P	C	C	P	C	N	N	C	P	C	C	C	C	C	C	C	N	N
rush, toad	N	N	N	-	-	N	N	C	C	C	C	-	-	N	N	C	N	N
shepherd's-purse	N	P	P	C	C	N	N	C	P	P	C	C	C	N	P	N	N	N
smartweed, swamp	P	C	C	P	C	N	N	C	C	C	C	-	C	N	P	N	N	N
sowthistle	P	C	C	C	C	N	N	C	N	N	N	-	-	N	C	N	N	N
speedwell, thymeleaf	N	N	N	N	N	N	N	C	N	N	N	N	N	N	N	P	N	N

spurge, petty	N	N	N	N	-	N	N	-	-	C	C	-	-	C	C	-	N	N
spurry, corn	N	N	N	N	N	N	N	C	C	N	N	-	-	-	C	C	N	N
starthistle, yellow	N	N	N	P	C	N	N	-	C	N	N	-	-	-	C	N	N	N
sunflower, wild	C	C	C	C	C	N	N	C	C	C	C	C	C	N	P	N	N	N
swinecress	N	N	P	N	P	N	N	C	C	C	C	-	-	N	P	N	N	N
willowherb, panicle	P	C	C	N	-	N	N	-	-	C	C	-	-	N	N	-	N	N

Source: (UC IPM, 2009)

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Table 2-7 Susceptibility of Grass Weeds in Seedling Alfalfa to Herbicide Control

	POSTEMERGENT																		
GRASS WEEDS	**24DB*[1]**	**24DB*[2]**	**24DB*[3]**	**24DB*[4]**	**BRO[1]**	**BRO[2]**	**CLE[1]**	**CLE[2]**	**GYL[4]**	**HEX**	**IMA[1]**	**IMA[2]**	**IMZ[1]**	**IMZ[2]**	**PAR*[1]**	**PAR*[2]**	**PRO**	**SET[1]**	**SET[2]**
barley, hare	N	N	N	N	N	N	C	C	C	N	N	N	C	C	P	P	C	C	C
barnyardgrass	N	N	N	N	N	N	C	C	C	N	C	C	C	C	P	P	N	C	C
bluegrass, annual	N	N	N	N	N	N	P	C	C	P	N	P	N	P	P	C	C	N	N
brome, ripgut	N	N	N	N	N	N	C	C	C	N	N	N	C	C	P	P	C	P	-
canarygrass, hood	N	N	N	N	N	N	C	C	C	N	N	P	C	C	N	P	N	C	C
fescue, rattail	N	N	N	N	N	N	-	C	C	N	N	N	P	P	P	P	-	N	P
foxtail, yellow	N	N	N	N	N	N	P	C	C	N	N	P	C	C	P	P	N	C	C
goosegrass	N	N	N	N	N	N	P	P	C	N	N	N	N	N	N	N	N	P	P
oat, wild	N	N	N	N	N	N	C	C	C	N	P	P	C	C	P	P	C	C	C
punagrass	N	N	N	N	N	N	P	C	P	N	N	N	N	N	N	N	-	P	C
ryegrass, Italian	N	N	N	N	N	N	C	C	C/P^	N	N	N	C	C	P	C	C	C	C
wheat, volunteer	N	N	N	N	N	N	C	C	C	N	N	P	C	C	P	C	C	C	C

Source: (UC IPM, 2009)

Ratings Legend

C = control (100-80% control)
P = partial control (79-65% control)
N = no control (less than 65% control)
- = no information

Chemical Legend

24DB*[1] = 2,4-DB* (Butoxone 0.5, etc.)
24DB*[2] = 2,4-DB* (Butoxone 0.75, etc.)

IMA[1] = imazethapyr (Pursuit 0.063)
IMA[2] = imazethapyr (Pursuit 0.094)

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24DB*[3] = 2,4-DB* (Butoxone 1.0, etc.)
24DB*[4] = 2,4-DB* (Butoxone 1.5, etc.)
BRO[1] = bromoxynil (Buctril 0.25)
BRO[2] = bromoxynil (Buctril 0.375)
CLE[1] = clethodim (Prism 0.1)
CLE[1] = clethodim (Prism 0.1)
GLY+ = glyphosate (Roundup WeatherMax)
HEX = hexazinone (Velpar 0.25)
IMZ[1] = imazamox (Raptor 0.032)
IMZ[2] = imazamox (Raptor 0.047)
PAR*[1] = paraquat* (Gramoxone 0.125)
PAR*[2] = paraquat* (Gramoxone 0.25)
Pro* = pronamide (Kerb 1.0)
Set[1] = sethoxydim (Poast 0.375)
Set[2] = sethoxydim (Poast 0.5)

Comments

NOTE: Weed size and spray coverage impact weed control as will herbicide rate, adjuvant type, spray volume, and environmental conditions.
* Permit required from county agriculture commissioner for purchase or use.
+ for Roundup-ready (RR) alfalfa only
^ glyphosate (Roundup) resistance developing in many crops

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Table 2-8 Susceptibility of Weeds in Seedling Alfalfa to Herbicide Combination Control

	POSTEMERGENT COMBINATIONS										
BROADLEAF WEEDS	**BRO IMA[1]**	**BRO 24DB[*2]**	**BRO SET[3]**	**BRO CLE[4]**	**BRO HEX[5]**	**IMA 24DB[*6]**	**IMA CLE[7]**	**IMA SET[8]**	**SET 24DB[*9]**	**IMA PAR[*10]**	**IMA HEX[11]**
burclover	N	N	N	N	P	N	N	N	N	N	P
buttercup	C	N	N	N	N	C	C	C	N	C	C
celery, wild	N	N	N	N	N	N	N	N	N	P	P
chickweed	C	N	N	N	C	C	C	C	N	C	C
cocklebur	C	C	C	C	C	C	C	C	C	C	C
dock, curly (seeding)	C	C	N	N	N	P	N	N	C	N	P
doverfoot	C	P	N	N	N	C	C	C	P	C	C
fiddleneck	C	C	C	C	C	N	N	N	N	P	P
fillarees	C	N	N	N	P	P	P	P	N	C	C
groundsel, common	C	C	C	C	C	N	N	N	C	C	C
henbit	P	N	N	N	P	N	N	N	N	N	N
jimsonweed	C	C	C	C	C	C	C	C	C	C	C
knotweed (seedling)	P	P	P	P	P	C	P	P	P	P	C
lambsquarters	C	C	C	C	C	C	N	N	C	C	C
lettuce, miners	C	N	N	N	P	C	C	C	N	C	C
lettuce, prickly	C	C	C	C	C	C	N	N	C	C	N
mallow, little (cheeseweed)	C	N	N	N	N	C	P	P	N	C	C
milkthistle	P	P	N	N	N	N	N	N	P	P	-
mustard, black	C	C	C	C	C	C	C	C	P	C	C
nettle, burning	C	N	N	N	N	C	P	P	N	P	C
nightshade, hairy	C	C	C	C	C	C	C	C	C	C	C
oxtongue, bristly	P	P	C	C	P	-	N	N	P	-	P
pineappleweed	P	C	C	C	-	P	N	N	C	C	-
pigweed, redroot	C	C	P	P	C	C	C	C	C	C	C
radish, wild	C	P	P	P	P	P	P	P	P	P	C
rockpurslane, desert	C	N	N	N	N	C	C	C	N	C	C
rocket, London	C	C	C	C	P	C	C	C	C	C	C
rush, toad	C	-	-	-	C	C	C	C	N	C	C
shepherd's-purse	C	C	C	C	C	P	P	P	P	P	C
smartweed, swamp	C	C	C	C	C	C	C	C	C	C	C
sowthistle	C	C	C	C	C	N	N	N	C	C	N
speedwell, thymeleaf	N	N	N	N	N	N	N	N	N	N	N
spurge, petty	C	N	N	N	N	C	C	C	N	C	C
spurry, corn	N	N	N	N	C	N	N	N	N	C	C
starthistle, yellow	C	C	C	C	C	N	N	N	N	C	-
sunflower, wild	C	C	C	C	C	C	C	C	C	C	C
swinecress	C	N	P	P	-	C	C	C	P	C	C
willowherb, panicle	C	C	-	-	-	C	C	C	C	C	C
GRASS WEEDS											
barley, hare	N	N	C	C	N	N	C	P	C	P	N
barnyardgrass	C	N	C	C	N	C	C	C	C	C	C
bluegrass, annual	N	N	N	P	N	N	C	N	N	C	P
brome, ripgut	N	N	P	C	N	N	C	P	P	P	N
canarygrass, hood	P	N	C	C	N	P	C	C	C	P	P
fescue, rattail	N	N	N	-	N	N	-	N	N	P	N
foxtail, yellow	P	N	C	C	N	N	C	C	C	P	P

BROADLEAF WEEDS	BRO IMA[1]	BRO 24DB[2]	BRO SET[3]	BRO CLE[4]	BRO HEX[5]	IMA 24DB[6]	IMA CLE[7]	IMA SET[8]	SET 24DB[9]	IMA PAR[10]	IMA HEX[11]
goosegrass	N	N	P	N	N	N	P	P	P	N	N
oat, wild	P	N	C	C	N	P	C	C	C	P	P
punagrass	N	N	P	-	N	N	P	P	P	N	N
ryegrass, Italian	N	N	C	C	N	N	C	C	C	C	N
wheat, volunteer	P	N	C	C	N	N	C	C	C	P	P

Source: (UC IPM, 2009)

Ratings Legend

C = control (100-80% control)
P = partial control (79-65% control)
N = no control (less than 65% control)
- = no information

Chemical Legend

[1] = bromoxynil (Buctril 0.25) + imazethapyr (Pursuit 0.064)
[2] = bromoxynil (Buctril 0.25) + 2,4-DB*(Butoxone 1.0, etc.)
[3] = bromoxynil (Buctril 0.375) + sethoxydim (poast 0.375)
[4] = bromoxynil (Buctril 0.375) + clethodim (Prism 0.25)
[5] = bromoxynil (Buctril 0.25) + hexazinone (Velpar 0.125)
[6] = imazethapyr (Pursuit 0.063) + 2,4-DB*(Butoxone 0.5, etc.)
[7] = imazethapyr (Pursuit 0.063) + clethodim (Select Max 0.1)
[8] = imazethapyr (Pursuit 0.063) + sethoxydim (Poast 0.375)
[9] = sethoxydim (Poast 0.375) + 2,4-DB*(Butoxone 1.5, etc.)
[10] = imazethapyr (Pursuit 0.063) + paraquat* (Gramoxone 0.25)
[11] = imazethapyr (Pursuit 0.094) + hexazinone (Velpar 0.25)

Comments

NOTE: Weed size and spray coverage impact weed control as will herbicide rate, adjuvant type, spray volume, and environmental conditions.
* Permit required from county agriculture commissioner for purchase or use.

2.4.4 Non-herbicide weed management practices

Weeds can also be controlled through cultural and mechanical methods. Weed management options include:

- Rotation of crops
- Winter crops in rotation
- Mowing or flash grazing
- Companion crops/co-cultivation/interseeding/nurse crop
- Cover crops (smother crops) (prior to planting alfalfa)

- Field scouting for early detection
- Monitor for weed species and population shifts
- Mechanical removal
- Adjusting harvest frequency
- Burning
- Tillage cultivation (seed production only)

Forage harvest removes weed biomass and developing weed seedlings. Regular forage harvest at late vegetative/mid bud stage combined with healthy competitive stands, effectively manage many key weed species, especially during the middle stages of a specific stand. Crop rotations can help maintain soil fertility, reduce soil erosion, avoid pathogen and pest buildup, adapt to weather changes, avoid the effects to reduce growth of one plant due to chemicals released by another, and increase profits. Alfalfa is also used in crop rotation because it provides nitrogen to the soil, which decreases fertilizer inputs in other rotations. Perennials and annuals promote and restrict different weeds, so rotating perennial and annual crops helps control weeds in general. Rotating alfalfa is also advised because mature alfalfa is autotoxic to seedling alfalfa (USDA APHIS, 2009, p. 74-75).

2.5 HERBICIDE RESISTANCE

Herbicide resistance is "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type" (WSSA, 1998).

Herbicide resistance is a result of natural selection. Plants within a population of a given species are not all identical; they are made up of "biotypes" with various genetic traits. Biotypes possess certain traits or characteristics not common to the entire population. Herbicides, that suppress or kill weeds, can exert selection pressure on weed populations. When a herbicide is applied, the plants with genes that can confer resistance to it, which had no special survival qualities before the herbicide was introduced, become the survivors who are then able to reproduce and pass on their genes. With repeated application of the same herbicide and no other herbicide or weed control practice, the resistant biotype becomes the dominant biotype in that weed community. In the mid-1950s, Harper (1957) theorized that annual, repeated use of any herbicide could lead to shifts in weed species composition within a crop-weed community. Similarly, Bandeen et al. (1982) suggested that a normal variability in response to herbicides exists among plant species and tolerance can increase with repeated use of an herbicide.

Indeed, as of June 27, 2010, 341 herbicide resistant weed biotypes have been reported to be resistant to 19 different herbicide modes of action (Heap, 2010). Glyphosate-resistant weeds account for 5 percent of the herbicide resistant biotypes (as documented on the www.weedscience.org website) while weeds resistant to herbicides that inhibit acetolactate synthase (ALS), such as Raptor and Pursuit, account for 31 percent of the herbicide resistant biotypes (Wilson, 2010a, p. 6).

Figure 2-2 shows the increase in herbicide resistant biotypes with time. Among the herbicides commonly used in conventional alfalfa, Prism, Poast and Select are ACCase inhibitors; Raptor and Pursuit are ALS inhibitors; Butyrac and Butoxone are growth regulators, and Karmex and Direx are in the category of photosynthesis inhibitors. Figure 2-2 shows only the number of confirmed resistant biotypes. The total extent and distribution of resistant biotype varies widely. Details of herbicide resistant weed in alfalfa are discussed in Section 3.11.

For as long as herbicide resistance has been a known phenomenon, public sector weed scientists, private sector weed scientist and growers have been identifying methods to address the problem. For instance, when a farmer uses multiple weed control tools, each effective on a particular species, herbicide resistance biotypes will be controlled and the resistance biotype generally will not become the dominant biotype within a population (Gunsolus, 2002; Cole, 2010a, p. 4). By contrast, weed resistance is known to occur most rapidly in areas where there is a sole reliance

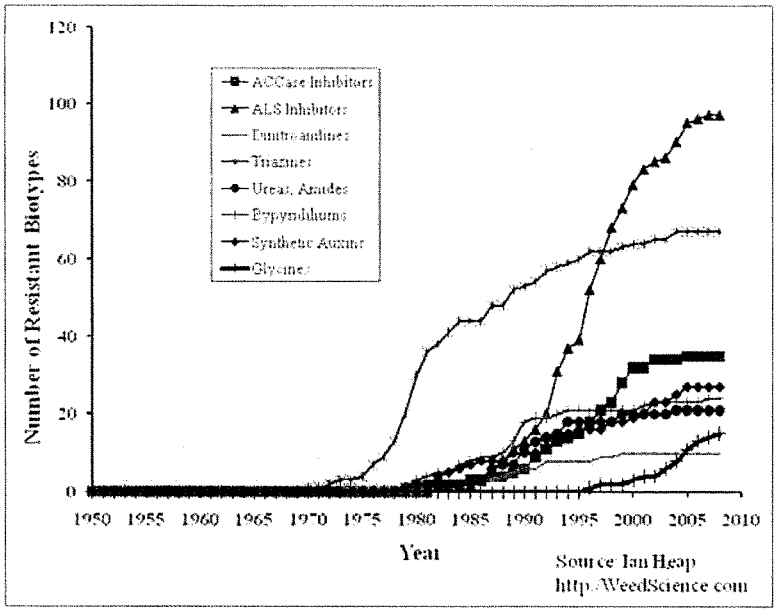


Figure 2-2. Herbicide resistance worldwide

on a single herbicide used repeatedly over multiple crop generations for the management of a specific weed spectrum.

When a grower encounters a biotype that is resistant to an herbicide he is using, the grower must use an alternate method of weed control. Management practices that can be used to retard the development of resistance, such as those routinely used by alfalfa growers, include herbicide mixtures, herbicide rotation, mowing, and crop rotation.. The WSSA reports: "Weed scientists know that the best defense against weed resistance is to proactively use a combination of agronomic practices, including the judicious use of herbicides with alternative modes of action either concurrently or sequentially" (WSSA, 2010b).

2.6 SEXUALLY COMPATIBLE RELATIVES INCLUDING CONSPECIFIC FERAL AND VOLUNTEER ALFALFA

2.6.1 Native sexually compatible relatives

There are no sexually compatible native relatives of alfalfa present in the U.S. (Mallory-Smith and Zapiola, 2008; Van Deynze et al., 2008, p. 7). No native members of the genus Medicago are found in North America (USDA APHIS, 2009, p. 20).

2.6.2 Feral and volunteer alfalfa

Feral crops are those that have become de-domesticated. Based on available data, de-domestication has occurred in only a few crops. These feral crops are of minor importance compared with other weeds (Gressel, 2005). In North America, the feral plants that cause much of the economic damage are imported horticultural plants; for example, Japanese privet, Japanese honeysuckle and kudzu (Gressel, 2005).

For purposes of this ER, unmanaged alfalfa planted for pasture, grazing or road-side reclamation (and similar uses) is also considered feral as, once established, they receive no or minimal agronomic inputs (e.g., clipping). Cultivated and feral alfalfa populations source to the same *Medicago sativa* L. germplasms that were repeatedly introduced to North America over a 400 year period.

Rogan and Fitzpatrick (2004) summarize the extent of feral populations in six major alfalfa-producing States—California, Washington, Idaho, Wyoming, Nevada, and Montana—confirming that minor feral populations do exist in areas where alfalfa seed or forage is produced (USDA APHIS, 2009, p. 22). Compared to cultivated alfalfa, feral alfalfa occurs at a relatively low density and scale. Kendrick et al. (2005) performed a biogeographic survey of five states (California, Idaho, Pennsylvania, South Dakota, and Wisconsin) in 2001 and 2002 and found that feral plants were not present or were sparse in most agricultural areas. Approximately 22 percent of the surveyed sites had dispersed or patches of feral alfalfa within 1.25 miles of cultivated alfalfa (Kendrick et al. 2005; Van Deynze et al., 2008). Relative to the geographies in which only forage is grown, areas with seed production fields were found to have fewer feral alfalfa plants growing in roadsides. Using herbicides or mechanical means, feral alfalfa can be and is controlled by certified alfalfa seed growers as a standard method to help assure isolation from other sources of pollen during varietal seed production (AOSCA, 2009).

Feral, or naturalized, alfalfa populations can escape agricultural fields and multiply by natural regeneration throughout the U.S. Feral alfalfa can be found at air fields, canals, cemeteries,

ditch banks, fence rows, highways, irrigation ditches, pipelines, railroads, rangeland, right-of-ways, roadsides, and wastelands. Alfalfa plants that are not part of cropping systems generally have no regular external inputs like irrigation, herbicides, insecticides, and fertilizers. All feral alfalfa in the U.S., like alfalfa under cultivation, originated from introduced varieties.

In general, survival without management inputs requires feral plant populations to have traits that may differ from those of cultivated plants. The most common traits include:

- variety of pollinators,
- continuous seed production,
- considerable seed output,
- seeds produced in several habitats,
- seed dispersal over short and long distances,
- seed dormancy (ability to form a seedbank),
- broad germination requirements,
- discontinuous germination,
- rapid vegetative growth,
- ability to withstand competition,
- tolerance to unfavorable biotic and abiotic conditions, and
- rapid flowering

A portion of alfalfa seeds may be temporarily impervious to water; these are "hard" seeds. The hard seeds may decay in soil or lay un-germinated (dormant) for a period of time (e.g., a few weeks to several years). Gradually, the hard seed coat ages and the seed will germinate or decay. Alfalfa develops small fragile seedlings that if successfully established may become volunteers in subsequent crops or in unmanaged areas. Hard seed likely contribute few volunteer plants after one year, as, alfalfa seeds generally do not persist for more than one year in field soil (Albrecht et al., 2008). Data for persistence of hard seed in seed production fields is given and discussed in Van Deynze et al. (2008), this confirms Albrecht et al. where studies were done in forage plantings in the Midwest. To guard against hard seed carryover, seed growers take steps to eliminate residual alfalfa volunteers prior to planting (Putnam and Undersander, 2009, attached as Appendix I). AOSCA varietal purity standards (2009) require

land history of 2 or 4 years without alfalfa cultivation, for the Certified and Foundation alfalfa seed generations, respectively. Little to no secondary seeds are formed on hay crop stems because they are harvested in their juvenile stage (weeks before any new, viable seed is formed). A mature alfalfa stand is highly competitive and highly autotoxic to fragile, emerging secondary seedlings. Therefore, secondary seedlings are a very unlikely avenue for effective gene flow into existing solid-seeded alfalfa plantings. The autotoxic reaction and inter-plant competition severely limit germination and seedling vigor of alfalfa sown or dropped into existing or newly terminated alfalfa stands. Solid-seeded cultivated alfalfa fields do not successfully self-seed. Attempts to thicken existing alfalfa stands by deliberately inter-planting new seed into them typically fail, which is why most agronomists do not recommend the practice (Canevari et al., 2000; USDA APHIS, 2009, p. 18-19, 100).

Several scientists have reported that volunteer GT plants could become a problem in rotational crops when both rotational crops are GT, however none provided specific information or data (e.g., Cerdeira and Duke, 2006; Owen and Zelaya, 2005; York et al, 2004; NRC, 2010). RRA volunteers would be expected to be more of concern in crops grown for seed, such as corn and soybeans. Volunteer alfalfa plants—whether conventional or RRA—are controlled by use of mechanical means (e.g., tillage) or by application of several registered non-glyphosate broad-leaf herbicides. Feral alfalfa can also be controlled using these practices, or with glyphosate.

2.7 FOOD, FEED AND OTHER ALFALFA USES

Both food (sprouts, dietary supplements, and herbal or homeopathic medicine) and animal feed (hay, haylage, or silage) are derived from alfalfa.

Alfalfa forage, primarily harvested as hay or haylage, is used as a source of fiber and protein in animal diets. Most alfalfa forage is fed to dairy or beef cattle, but can also be an important part of the diet for horses, sheep and goats.

A small fraction of alfalfa seeds are used to produce sprouts for human consumption. Any alfalfa seed for sprouts must be certified as having been produced to food-grade specifications and therefore food-grade seed is grown and distributed in an entirely separate channel from that for general use, non-food-grade planting seeds. Food-grade seeds for sprouts are produced throughout the world, but the major suppliers are Canada, Italy, U.S. and Australia. Sprouts are cultivated from clean raw (non-coated, untreated) seeds in controlled environment sprouting chambers for approximately 5 to 10 days before sale to consumers.

FDA and equivalent regulatory bodies in Japan, Korea, Canada, Australia/New Zealand, etc., have granted full approval for the use of RRA as a food (see Section 3.11). Monsanto and FGI have developed the RRA varieties for field planting purposes (only), and as such the companies do not intend nor allow (give license to) any seed growers or seed purchasers to use RRA varieties for food-grade sprout production (Hubbard, 2008; USDA APHIS, 2009, p. 18).

2.8 PHYSICAL AND BIOLOGICAL ISSUES

The affected environment for land use, air quality, water quality, ecology, threatened and endangered species, and other sensitive wildlife is the alfalfa producing areas and the seed producing regions. The affected environment for climate is global, as impacts on climate change are a global issue.

2.9 SOCIOECONOMICS AND HEALTH

The affected environment for socioeconomic issues includes those individuals who could potentially be economically impacted if their food or agricultural products are adversely affected by RRA, and those who could be economically impacted if RRA becomes a deregulated article. Potential impacts to the first group are discussed primarily in Section 3.10 and impacts to the second group are discussed in Section 3.15. The potential for health impacts to individuals who may come into contact with RRA or alfalfa seeds or other products derived from RRA is discussed in Sections 3.10 and 3.14. Health effects of potential exposure to herbicides are discussed in Section 3.14.

SECTION 3.0 ENVIRONMENTAL CONSEQUENCES

3.1 PLANT PATHOGENIC PROPERTIES AND UNINTENDED EFFECTS

APHIS previously determined, based on scientific analysis and in accordance with its obligations under the PPA, that RRA does not exhibit plant pathogenic properties (USDA APHIS, 2009).

APHIS considered the potential for the transformation process, the introduced DNA sequences, or their expression products to cause or aggravate plant disease symptoms in RRA and its progeny or in other plants.

APHIS also considered whether data indicate that unintended effects would arise from the genetic engineering of these plants. APHIS considered information from the scientific literature as well as data provided by Monsanto/FGI in their petition that was developed from their field trials (USDA APHIS, 2009).

Based on the analysis summarized below, there are no impacts resulting from plant pathogenic properties, introduced or aggravated disease symptoms, or unintended effects under any of the alternatives. Details of the Monsanto/FGI studies are included in the petition (Rogan and Fitzpatrick, 2004).

3.1.1 Background

Plant genetic modification

Plant genetic modification by humans ranges from the simple approach of directed selection – where seeds of plants with desired traits are saved and replanted – to complex methods such as the use of rDNA (see definitions on next page). APHIS regulations define genetic engineering as genetic modification through the use of rDNA technology.[40] Crossing (and then recrossing) two sexually compatible plants by taking the pollen from one plant and brushing it onto the pistil of another remains the mainstay of modern plant breeding (IM/NRC, 2004). Both more traditional, "conventional breeding" and rDNA methods can involve changes in the frequency, sequence, order, and regulation of genes in a plant and can use many of the same enzymes. However, with conventional breeding all the tens of thousands of genes in the plant are involved, and with the rDNA method only a few genes are involved. In classical breeding, crosses can be accomplished only between closely related species, and therefore only traits that are already present in those species can be targeted. In contrast, the rDNA approach can

[40] 7 C.F.R. § 340.1.

use genes from any living organism, thus opening the door to vast potential in trait development (Lemaux, 2008, p. 774; AMA, 2000).

Other examples of plant genetic modification include cell fusion (the protective cell wall is stripped and cells are fused by some external force) and induced mutagenesis (inducing mutations in seeds by ionizing radiation or carcinogenic chemicals) (Ronald and Adamchak p. 88). Mutagenic techniques, which have been in use since the late 1920s, create random mutations and are limited by their inability to target a desired trait (FDA, 1992; Lundqvist, 2009, p. 39).

Agrobacterium

Agrobacterium tumefaciens (*Agrobacterium*) is a soil microbe that has been called "nature's own genetic engineer" because of its ability to transfer a fragment of its own DNA into a host plant (AMA, 2000). (See definitions at right.) The transferred DNA is stably integrated into the plant DNA, and the plant incorporates and expresses the transferred genes. The transferred DNA (T-DNA) reprograms the host plant cells to grow into callus tissue and produce certain amino acid derivatives that are a food source for the *Agrobacterium.* On a macro scale, the callus tissue growth is called crown gall disease. In the early 1980s scientists developed strains of *Agrobacterium* with T-DNA that lacked the disease-carrying genes ("disarmed" *Agrobacterium*). *Agrobacterium* transformation system has been utilized in the development of a large number of genetically engineered plants in commercial production (IM/NRC, 2004, pp. 28-29). The method uses a DNA molecule called a **vector** that serves as a carrier to insert T-DNA that contains specific genetic elements. These genetic elements are organized into a **gene cassette**, which consists of a gene encoding for a single biological function plus other genetic elements necessary for the expression of that gene when introduced into the plant. Other elements in the gene cassette include a **promoter**, which can be thought of as the "on switch" for the gene encoding for the desired trait; and a targeting sequence, which makes sure the gene product, typically a protein, ends up in the right location within the cell (such as the chloroplast).

Unintended effects from breeding

Most crops naturally produce allergens, toxins or other antinutritional substances; these often serve the plant as natural defense compounds against pests or pathogens (FDA, 1992). Plant breeders may monitor the levels of antinutritional substances relevant to their crop. For

example, lignin is an indigestible cell wall component that limits forage digestibility. Alfalfa breeders typically monitor lignin content of plants in their breeding programs.

Scientists from the Institute of Medicine (IM) and the National Research Council (NRC) ranked breeding methods according to their relative likelihood of producing unintended effects, which they hypothesized would correspond to the degree of genetic disruption associated with the method. Selection from a homogeneous population was ranked at one end of the spectrum (less likely to produce unintended effects) and induced mutagenesis (from chemicals or radiation) was ranked at the other end (more likely). *Agrobacterium* transfer of rDNA was among the methods ranked in between (IM/NRC, 2004, Figure ES-1). Recent studies in Europe comparing transgenic and conventional barley suggest that conventional breeding may cause more unintended effects than rDNA methods, likely because of the very large number of genes that are affected in conventional breeding techniques (Sonnewald, 2010).

Glyphosate tolerance

As discussed in Section 2, glyphosate acts by inhibiting the action of the enzyme EPSPS, in plants. EPSPS is a catalyst for a reaction necessary for the production of certain amino acids essential for plant growth. When plants are treated with glyphosate the EPSPS enzyme is inhibited, they cannot produce the amino acids needed for continued growth and eventually die. The EPSPS protein and the reaction it catalyzes are present in all plants and microbes. There are variations in the amino acid sequence of EPSPS among different plants and bacteria. GT is achieved by introducing an EPSPS enzyme, termed CP4 EPSPS, that is not inhibited in the presence of glyphosate. An *Agrobacterium* strain (designated CP4) was the source of the CPR EPSPS gene that encodes for the CP4 EPSPS enzyme (Rogan and Fitzgerald, 2004). The CP4 EPSPS enzyme carries out the same enzymatic reaction in the plant as the native EPSPS; however, when plants that contain the CP4 EPSPS are sprayed with glyphosate, they are able to continue to produce the essential amino acids needed for plant growth. The objective of the genetic modification in RRA was to simplify and improve weed management practices in alfalfa by the addition of the CP4 EPSPS enzyme to confer tolerance to glyphosate (USDA APHIS, 2005).

Transformation system

RRA was developed using a disarmed Agrobacterium-mediated transformation system of sterile alfalfa leaflets. Post-transformation, the Agrobacterium were eliminated from tissues by a 7-week culture on antibiotic-containing medium. Glyphosate was used to select for transformed

tissues containing the EPSPS gene construct. This technique of using a disarmed Agrobacterium strains followed by selection has a 20-year history of safe use and has been used for transformation of a variety of plant species and tissues. The plant material used for development of RRA was FGI proprietary alfalfa clone R2336 from a high yielding, fall dormant breeding population. The initial plants, selected for tolerance to glyphosate, were designated J101/J163, and various populations were developed from these events to provide the data presented in the petition (USDA APHIS, 2005).

DNA sequences inserted into RRA

Data supplied in the petition and reviewed by APHIS indicate that the CP4 EPSPS expression cassette inserted into alfalfa events RRA contains the CP4 EPSPS coding sequence under the regulation of the 35S promoter, a heat shock protein intron (HSP70), a chloroplast transit peptide (CTP2) sequence and a E9 3' polyadenylation sequence. The CTP2 CP4 EPSPS coding region used to produce events J101/J163 is the same as that employed in several other RR crops such as soybean, which have been previously reviewed and granted non-regulated status by the USDA. The CP4 EPSPS gene does not cause disease and has a history of safe use in a number of GE plants (e.g., corn, cotton, and soybean varieties).

3.1.2 Evaluation of intended effects

Analysis of inheritance

Data were provided by Monsanto/FGI and reviewed by APHIS that demonstrate stable integration and inheritance of the EPSPS gene cassette over several breeding generations. Statistical analyses show that GT is inherited as a dominant trait in a typical Mendelian manner (M).

Analysis of gene expression

Monsanto/FGI collected data on EPSPS protein concentrations from field trials conducted at several locations. The companies determined EPSPS protein concentrations using standard laboratory techniques. EPSPS concentrations on a fresh weight basis averaged 257 micrograms (µg)/gram in plants with event J101, 270 µg/gram in plants with event J163, and 252 µg/gram in plants from the population containing both events J101/J163. EPSPS is ubiquitous in plants and microorganisms and has not been associated with hazards from consumption or to the environment. Crops that contain this protein and have been granted non-regulated status have included corn, soybean, cotton, rapeseed, and sugar beet (USDA APHIS, 2010a). In 2009, significant acreages of corn (59 million acres or 68 percent of the total), upland

cotton (6.3 million acres or 71 percent of the total) and soybean (70.5 million acres or 91 percent of the total) grown in the U.S. were planted with herbicide tolerant varieties (USDA NASS, 2010c). Although these acreages include all herbicide tolerant varieties, GT ones (containing CP4 EPSPS) predominate. All have also undergone FDA review (FDA, 2010).

Analysis of the intended trait

Monsanto/FGI conducted numerous field trials to evaluate RRA in different environments. Standard field trials evaluated (1) agronomic performance, (2) disease and pest resistance performance, and (3) seed multiplication. Agronomic practices used to prepare and maintain each field trial were characteristic of each representative region. Where the glyphosate herbicide Roundup® was used in trials, no negative impacts from application were noted (Rogan and Fitzpatrick, 2004).

3.1.3 Evaluation of possible unintended effects

Disease and pest susceptibility

On the basis of pest and disease susceptibility data reviewed by APHIS, RRA populations were no different from control or conventional alfalfa populations in the prevalence of or response to diseases or pests. Since the deregulation of RRA in 2005, there have been no reports of any change in disease or pest interactions in RRA compared to conventional alfalfa (USDA APHIS 2009).

During field trials from 1999 to 2003 and after deregulation of RRA in 2005, RRA has been grown over a broad geographic distribution of sites in the U.S. This has exposed RRA to a wide range of naturally occurring diseases. The principal alfalfa diseases in the U.S. affect the foliar, crown, root, vascular, and seedling health of alfalfa plants. Fungi are the primary pathogen type involved in most alfalfa diseases. Nematodes, bacteria, viruses, and other microbes can also reduce alfalfa production. The major economic diseases that occurred during field trials included: seedling damping-off (fungal genera such as *Pythium*, *Phytophthora*, *Aphanomyces*); foliar diseases (fungal genera such as *Leptosphaerulina*, *Colletotrichum*, *Peronospora*, *Phoma*, *Stemphylium*, *Cercospora*, and stem nematodes like *Ditylenchus*); and root rots, vascular wilts and crown diseases (fungal genera such as *Phytophthora*, *Aphanomyces*, *Verticillium*, *Fusarium*, *Phoma*, and bacterial wilt caused by *Clavibacter*) (USDA APHIS, 2009).

The major insect pest species affecting alfalfa vary between regions in the U.S. During field trials and after deregulation of RRA in 2005, RRA has been exposed to a wide range of naturally occurring insect pests. The principal economic insects included: potato leafhoppers

(*Empoasca fabae*), aphids [pea (*Acyrthosiphon pisum*), blue (A. kondoi) and spotted alfalfa aphids (*Therioaphis maculata*)], alfalfa weevil (*Hypera postica*), lygus bugs (*Lygus* species), other plant bug species (family *Miridae*) and alfalfa caterpillars (various Lepidopteran species). The disease and pest susceptibility observations for the field trials were provided to APHIS. These observations consistently showed no significant differences in the disease and insect susceptibility between events J101/J163 (or synthetic populations developed using both events) and the conventional control lines or commercial reference varieties. Although occasional differences were noted at some field sites, there were no concurrent trends of differences across field sites or years. This suggests that these differences were likely due to random variation. Additional disease ratings taken as part of the phenotypic comparative studies also indicate that diseases and pest incidence are unchanged in RRA compared to the control and that RRA is not more or less susceptible to pests or diseases than conventional alfalfa. Commercial experience and additional research conducted since the 2005 deregulation decision are consistent with the findings from field trials during the regulated period (USDA APHIS, 2009).

Gene silencing

In evolutionary biology, a homologous trait is one derived from a common ancestor that appears in multiple species. Homology may be manifested on a macro scale, for example, in the similarity in mammal forelimbs, and on a genetic scale, in DNA sequences. Al-Kaff et al. (1998) have noted gene silencing effects when transgenic plants have been infected by a virus with DNA sequence homology to a portion of the introduced genes. The only virus-derived DNA in the introduced gene cassette is the promoter, which is from the figwort mosaic virus. None of the viral diseases of alfalfa is related to figwort mosaic virus (Whitney and Duffus, 1986), so silencing of the EPSPS gene would not be expected and has not been observed.

Compositional changes

The composition of forage produced by RRA plants containing either event J101, J163, or the paired events J101 X J163 was measured and compared to the composition of control and conventional alfalfa forage (Rogan and Fitzpatrick, 2004). Monsanto/FGI analyzed alfalfa for compositional changes as part of their submission to FDA in the consultation process. While FDA uses these data as indicators of possible nutritional changes, APHIS views them as general indicators of possible unintended changes.

Compositional analyses evaluating carbohydrates, protein, ash, minerals, fiber, lignin, fat, and 18 amino acids (a total of 35 different components) identified three statistically different values compared with the control population for J101, seven statistically different values for J163, and 11 statistically different values for the paired J101 X J163 population. However, all analyses fell within the 99 percent tolerance interval developed from the conventional varieties grown in the same locations, providing additional evidence that J101, J163 and the paired J101 X J163 populations do not exhibit unexpected or unintended effects (USDA APHIS, 2005).

3.2 WEEDINESS PROPERTIES AND FERAL CROPS

This section addresses two questions:

1. What are the weediness properties of alfalfa?
2. Is RRA any more likely to become a weed than conventional alfalfa?

For information on feral alfalfa or volunteer alfalfa, refer to Section 2.6.2.

3.2.1 Weediness properties of alfalfa

Alfalfa (*Medicago sativa* L.) is not listed as a serious weed in *A Geographical Atlas of World Weeds* (Holms et al., 1991) or as a weed in *World Weeds: Natural Histories and Distribution* (Holms et al., 1997), *Weeds of the North Central States* (http://www.aces.uiuc.edu/vista/html_pubs/WEEDS/list.html), *Weeds of the Northeast* (Uva et al.,1997), or *Weeds of the West* (Whitson et al., 1992). Alfalfa is not listed as a noxious weed species by the U.S. Federal Government (7 C.F.R. Part 360) and is not listed as a weed in the major weed references (Crockett, 1977; Holm, Pancho et al., 1979; Muenscher, 1980) (USDA APHIS, 2009).

Although feral (free-living) populations of alfalfa are fairly common and volunteers may occur among succeeding crops, alfalfa is not considered a serious weed, a noxious weed, or an invasive species[41] in the U.S. The Interactive Encyclopedia of North American Weeds, Version 3.0, includes alfalfa (NCWSS, 2005). But this reference does not indicate why alfalfa is considered a weed. It may be included based on its potential occurrence as an unwanted volunteer in agricultural settings (USDA APHIS, 2009 p. H-13).

[41] A species that is not native to a particular ecosystem and whose introduction does or is likely to cause economic damage or environmental harm or harm to human health. Executive Order 13112 – Invasive Species (1999); USDA National Agricultural Library, 2010.

3.2.2 RRA and weediness

Some scientists, for example, Ellstrand (2006), have raised the question of "unintended crop descendents from transgenic [GE] crops." Ellstrand states (p. 116): "The possibility of unintended reproduction by transgenic crops has raised questions about whether their descendents might cause problems. These problems have fallen into two broad categories: first, the direct feral descendents of the crops may prove to be new weeds or invasives, and second, that unintended hybrids between transgenic crops and other plants could lead to certain problems." This section discusses the weediness properties of RRA, and addresses the concern of direct descendents of the crop that "may prove to be new weeds or invasives." Hybridization is addressed in several later sections.

Alfalfa does not naturally hybridize with any wild relatives in North America. Having established that there are no related, sexually compatible wild relatives in the U.S., movement of the CP4 EPSPS gene can only occur to cultivated or feral alfalfa populations through pollination by bees, dropped seeds or seed admixtures.

RRA events J101/J163 were field tested in North America from 1999 to 2003 and planted commercially after deregulation in 2005. APHIS reviewed data on characteristics that might relate to or have an effect on increased weediness. These included seed dormancy, seed germination, seedling emergence, seedling vigor, spring stand, spring vigor, seed yield, vegetative growth or plant vigor, plant dormancy, growth habit, flowering properties, and effect on symbiotic organisms (USDA APHIS, 2009). No unusual characteristics were noted that would suggest increased weediness of J101/J163 plants relative to the control populations.

In a separate evaluation, the Canadian Food Inspection Agency (CFIA), whose responsibilities include regulation of the introduction of animal food and plants (including crops) to Canada, reached the same conclusion about the weediness potential of events J101/J163 compared with non-transgenic alfalfa. In 2005, the CFIA authorized the "unconfined release into the environment and livestock feed use of alfalfa events J101/J163" (CFIA, 2005). In its evaluation of events J101/J163, CFIA "determined that stand establishment, enhanced growth, vigour or stand longevity; changes in susceptibility to plant pests and diseases common to alfalfa; increases in forage and seed yield and increases in seed dormancy were within the normal range of expression of these traits currently displayed by commercial alfalfa varieties" (CFIA, 2005). The CFIA reached the following conclusions (CFIA, 2005):

> No competitive advantage was conferred to these plants, other than that conferred by tolerance to glyphosate herbicide. Tolerance to Roundup®

agricultural herbicides will not, in itself, render alfalfa weedy or invasive of natural habitats since none of the reproductive or growth characteristics were modified.

The above considerations, together with the fact that the novel traits have no intended effects on alfalfa weediness or invasiveness, led the CFIA to conclude that alfalfa events J101/J163 have no altered weed or invasiveness potential compared to currently commercialized alfalfa.

3.2.3 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impacts from RRA on weediness properties of alfalfa or feral alfalfa because new RRA would not be grown commercially.

Alternative 2: Partial Deregulation of RRA

APHIS has concluded that alfalfa does not exhibit weediness properties, and that RRA does not exhibit any altered weediness properties when compared with conventional alfalfa. Therefore, Alternative 2 would not impact the weediness characteristics of alfalfa.

Feral, non-RRA exists throughout the U.S. RRA does not exhibit any increased feral growth potential when compared to conventional alfalfa. Therefore, Alternative 2 would not affect the feral growth potential of alfalfa.

Under Alternative 2, RRA volunteers in crop production would be controlled by mechanical means (e.g., tillage) or by application of one of several registered non-glyphosate herbicides.

3.3 IMPACTS OF RRA FORAGE CROPS ON CONVENTIONAL AND ORGANIC FORAGE CROPS

This section considers the possibility of impacts from RRA forage crops on conventional and organic forage crops through gene flow (refer to Section 2.3 for a general discussion of gene flow), or by mixing in harvesting or transportation.

3.3.1 Pollen sources in forage production fields

As discussed in Section 2.3, alfalfa is a short-lived perennial crop plant that peaks in forage yield during the second and third year. In the hay production fields, alfalfa is grown for its high nutritional value for cattle and horses. The nutritional value is at its highest during the plant's young vegetative state. As the plant approaches full flower, its nutritional value decreases. Therefore, alfalfa grown for hay is managed to limit growth to the juvenile state. Most alfalfa hay in the U.S. is harvested before 10 percent of the stems have one or more open flowers. Thus, most forage fields are cut before most plants have produced any pollen and prior to when they

could be pollinated. This practice is widely recommended so that hay production and nutritional quality of the hay are optimized to maximize the farmer's economic productivity (USDA APHIS, 2009, p. 18-19, 100).

3.3.2 Potential for gene flow in forage production fields

Cross-pollination, if it occurred could potentially result in adventitious (inadvertent) production of embryos with the GT gene in a conventional or organic hay production field. Because alfalfa forage is typically managed for high quality and harvested before 10 percent bloom, and RRA forage producers are concerned with high quality, there is little potential for cross-pollination because the availability of pollen is minimized as a consequence of normal harvest activities. Furthermore, as mentioned in Section 3.3, in all but exceptional cases, native populations of bees are insufficient to effect economic levels of alfalfa seed pollination so they are augmented using cultured bee colonies. Unlike seed farmers, forage producers do not stock bees to produce the forage crop because they do not want or need pollination of their fields (USDA APHIS, 2009, p. 94; Rogan and Fitzpatrick, 2004).[42]

Nonetheless, if cross-pollination occurs in forage fields, the inadvertently pollinated plants are without gene flow consequence because they are almost always harvested before developing embryos mature to become viable seed. For effective gene flow from a RRA hay field to a conventional/organic hay field, each of the following must occur: (1) cross pollination between RRA and conventional plants; (2) delayed harvest allowing mature seed to form in the conventional/organic field; (3) mature RRA seed shattering and falling to the ground rather than being removed in forage harvest; (4) successful establishment of the new RRA seedling in the established conventional/organic alfalfa stand. Each of these requirements are unlikely and the combination of all of them happening is remote (Putnam, 2006; Van Deynze et al., 2008). Even in instances where weather or equipment failures delay harvesting of GT or non-RRA hay fields, there is little risk of unwanted GT gene flow into alfalfa production (Van Deynze et al., 2008). Alfalfa hay normally is harvested at or before first flower, 6 to 9 weeks before the ripe seed stage (Putnam, 2006; USDA APHIS, 2009 p.100). Regardless of proximity and management of a potential neighboring RRA hay field, a conventional/organic hay producer can eliminate any risk of potential pollen-mitigated RRA gene flow by simply harvesting prior to ripe seed stage.

[42] An exception to the foregoing are an unknown number of conventional alfalfa forage producers who inadvertently or by agreement allow a honeybee keeper to forage bees on the alfalfa field to produce a honey crop or brood. (See USDA, 2009 at Appendix O.) This would be unlikely for RRA forage producers because producers generally cut before blooms are useful for honey production. Honeybees would be unlikely to forage on RRA forage fields because bloom would be managed to maintain high quality forage.

3.3.3 Potential consequences of gene flow in forage production fields

As discussed above, because alfalfa hay is harvested well before ripe seed is produced, gene flow into or between RRA and conventional forage crops is expected to be de minimis.

3.3.4 Growing and marketing alfalfa

Dairy farmers would be the most likely users of RRA hay because they often depend on pure alfalfa stands that are free of weeds and grasses, whereas, beef cattle producers and horse owners typically feed their animals a mix of alfalfa-grass hay (Putnam, 2005; USDA APHIS, 2009, p. 17).

The dairy industry has widely accepted biotechnology-derived products, including recombinant bovine somatotropin (rBST) used to increase a cow's milk production, and GT crops such as corn, soybean, canola, and cottonseed meal used in feed. However, organic dairy producers have rejected GT crops and require hay from organically grown (non-RRA) crops. Although organic milk production has grown considerably, it is still less than one percent of the total U.S. production (Miller, 2005; Putnam, 2006). Additionally, some horse owners may prefer using non-RRA feed. However, because many horses are sickened or die from poisonous weeds in hay, many horse owners may choose RRA. Like organic milk production, organic beef production will require non-RRA alfalfa. However, organic beef production is less than one percent of the total beef production industry, and the non-organic beef industry is not expected to be sensitive to RRA (NCBA, 2005; Putnam, 2006).

Less than two percent of U.S. alfalfa hay production is exported (NAFA, 2008b). The export of alfalfa hay is of particular economic interest in the Columbia Basin of Washington and the Imperial Valley of California, where local exporters, supported by local hay producers, have developed this market. Seven states in the western U.S. export approximately 4-5 percent of their production (NAFA, 2008b). The largest importers of U.S. produced alfalfa hay are Japan, South Korea, and Taiwan. RRA has been approved for import into these three countries, and to Canada and Mexico. These five countries together represent over 90 percent of total U.S. hay exports (USDA APHIS, 2009, Table 3-15, p. 55). Although there are no regulatory barriers for the vast majority of this market, customer preference may demand testing for adventitious presence (AP) of the RRA trait in conventional hay sold for export. Protein-based test strips and testing protocol have been developed to test hay destined for AP sensitive markets (Woodward et al., 2006). These low-cost testing methods have been widely adopted by the export industry

to service the market segment requiring such tests, successfully avoiding any disruption of this important hay industry segment. (See USDA APHIS, 2009, p. Q-19).

3.3.5 Potential for and consequences of mechanical mixing

Alfalfa has small seeds that are planted, harvested, transported and processed for sale using large equipment designed especially for alfalfa seed crop handling. Seed growers and seed processing companies utilize lot segregation and equipment cleaning routines to remove seeds from equipment. Effective lot identification, segregation and equipment cleaning are practices required for the production of certified quality seeds. Vacuums, compressed air, sweeping, partial or complete disassembly, washing with water, etc. are effective means used to clean planting, harvesting, transportation, seed conditioning and seed treatment/coating equipment before or after use. These widely-adopted sanitation routines have been successful helping to assure negligible content of off-types, weed seeds, inert and non-crop mixtures (AOSCA, 2009).

As in all other agricultural production practices, there is possibility for mixtures between seed crops due to residual seeds in equipment, seed spillage, planting or lot blending mistakes or other human errors, however, the potential for impact is highly managed and therefore limited. Conventional seed crop handling practices vary widely and depend on the producer's end product quality targets (e.g., common seed to certified seed markets). Historically (i.e., 20-50 years ago), conventional alfalfa seed has sometimes been transported in trucks or trailers and seed escapes along transportation routes were commonplace. In contrast, first, all RRA seed growers are uniformly obligated under their FGI seed grower contracts to observe certified seed standards for seed identification, segregation and handling (AOSCA, 2009). Second, RRA seed producers are obligated to following the NAFA BMP requirements for contained transportation of seeds, equipment sanitation, and obvious seed lot labeling, etc. (see below). FGI provides training and the secure, labeled seed bins to each RRA grower and monitors compliance to the contract requirements. The NAFA BMP stipulates the following sanitation, identification and segregation requirements that must be followed for all RRA seed production:

> Sanitation requirements. Manage equipment to minimize seed mixture potential between different varieties and or variety types. Growers shall use dedicated equipment for planting and harvesting RRA seed production, when possible. Zero tolerance for seed admixture is not feasible under commercial production conditions; however, grower must take reasonable steps to assure that equipment is clean prior to and after use in the Roundup Ready seed field. *Examples*: Planter inspection, clean-down before and after use; Combine inspection, clean-down thoroughly before and after use; RRA seed bins may only be used for RRA seed; maintain physical separation of varieties in storage; inspect bins before use; Handle all like-trait varieties together; plan for harvest

> sequence of fields to maintain best separation of varieties by trait type; Clean all seed handling equipment to avoid mixing RRA and conventional seed; Return unused, unopened stock seed to the contracting seed company for credit; maintain in clean storage areas; When a contract harvester is used for RRA seed harvest, Growers must notify the contract harvester, in advance, that the field to be harvested is RRA (NAFA, 2008a).

Mechanical mixtures between lots in forage harvesting are possible, but mixing is limited in extent by the following common alfalfa forage practices (NAFA, 2008b): (1) Most hay (>75 percent) is harvested and fed on the same farm of production, therefore, growers know the type of variety planted in each field and fields are harvested separately. Fields lots are typically harvested separately and because each field may have a different feed quality level, the harvests are typically placed into separate storage areas for feeding. (2) Hay is not fungible during marketing, that is typically, each hay lot is identified, segregated and traceable to the field of origin during transportation, brokerage and sale. This is especially the case for organically certified crop products which must remain segregated from non-organically produced crops throughout all handling steps. (3) Some GE-sensitive hay marketers or feed processing facilities (meal, cubes, pellets) use commercial testing kits to test for the presence of the RRA trait in hay, thereby, offering a post harvest means to assure RRA hay segregation from non-RRA hay.

3.3.6 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impacts to growers of organic or conventional hay because RRA hay would not be grown commercially.

Alternative 2: Partial Deregulation of RRA

Based on the above discussions, RRA hay production under Alternative 2 would be expected to result in minimal impact for the following reasons:

- The reproductive biology of the alfalfa plant combined with normal harvest management for alfalfa forage provide for a de minimis likelihood of gene flow from one forage production field to another.
- Hay fields would be cut before seed is produced.
- A combination of geographic restrictions and gene flow mitigation measures (e.g harvest management requirements) significantly reduce the forage-to–seed gene flow interface. Gene flow mitigation measures (MT/SA and Technology Use Guide) are contractually

required for all RRA hay producers. These mitigation measures are practicable, contract-enforced, science-based, and market-driven. They have been designed to enable coexistence by mitigating all or nearly all unwanted gene flow between dissimilar crops and to aid in protecting non-GT, export, and organic hay and seed alfalfa crops. There have been negligible impacts since commercial seed production began in 2005 due to the efficacy of these BMP.

- Low-cost testing procedures are readily available to meet the needs of market requiring such tests.
- The conservative measures associated with this alternative include additional conservative forage/hay production restrictions that will ensure an extremely low likelihood and extent of gene flow from one production field to another.
- The biology, cultivation and marketing practices typically used in conventional alfalfa hay production limit the potential for physical and handling mixture to very low levels. The likelihood and extent of RRA and non-RRA mixtures are highly constrained by RRA seed grower practices stipulated and enforced under RRA seed grower contracts.
- RRA seed bag labeling and a unique purple seed colorant will be required for all RRA seed, which will notify RRA forage growers of the presence of the RRA trait and the limitations for product use. The colorant and bag labeling will reduce the likelihood of inadvertent planting by any organic or non-GE producer.
- As discussed in Section 3.8.1, conventional and organic alfalfa seed will continue to be available.

3.4 IMPACTS FROM RRA FORAGE CROPS ON NATIVE ALFALFA

As discussed in Section 2.6.1, no native members of the genus *Medicago* are found in North America. Therefore, there would be no impacts to native alfalfa under either alternative, because none exists.

3.4.1 Impacts

Because there are no native alfalfa populations in the U.S., there would be no impact with either alternative.

3.5 IMPACTS FROM RRA FORAGE CROPS ON FERAL ALFALFA POPULATIONS

The *M. sativa* species has naturalized populations in all 50 States (USDA APHIS, 2009, p. 23). Synchronous flowering of hay or seed production fields neighboring feral alfalfa will likely lead to cross-pollination. Feral alfalfa has the potential to act as a bridge for gene flow from GT alfalfa crops to non-GT alfalfa crops. First, the RRA hay or seed production field could serve as a pollen donor to the feral non-RRA. The subsequent feral GT offspring could then serve as the pollen donor to the non-GT hay or seed production field. Feral alfalfa near hay and seed fields should be controlled to avoid gene flow to the feral population (USDA APHIS, 2009, p. 101). Feral alfalfa in roadsides, ditchbanks and pastures is commonly controlled by mowing, disking, cultivation or the use of herbicides. Biogeographic survey data documents that, although climate and cropping practices are favorable for seed propagation, feral alfalfa is actually less abundant in seed producing geographies than other regions (Rogan and Fitzpatrick, 2004; Kendrick et al., 2005). Possible explanations for this observation are that, as seed producers follow seed certification standards requiring isolation, they routinely practice effective mitigations to control or prevent feral alfalfa populations (mowing, herbicides, cultivation). Also, alfalfa would not be intentionally planted in species mixtures in roadsides, pastures or rangelands where professional seed production occurs.

The barriers to gene flow into conventional/organic hay fields described in Section 3.3 also apply to pollen-mediated gene flow from RRA forage to feral alfalfa plants. These barriers also apply to pollen-mediated gene flow from feral alfalfa plants to conventional or organic alfalfa forage and will limit potential feral-to-hay gene flow to extremely low levels. Additionally, feral alfalfa will have low seed production plus damage from lygus bug and infection from seed-borne fungi when seed develops under damp conditions. (Putnam and Undersander, 2009 attached as Appendix I). The primary limitations to feral-to-seed gene flow is the relative paucity/abundance of pollen and proximity of pollinators in the field optimally managed for seed production, compared with a low density of feral plants growing some distance away and without the benefit of water, nutrient or pest control inputs (Van Deynze et al., 2008). A further mitigating factor is that Certified seed production requires a minimum 165 ft isolation between the seed production field and any feral alfalfa allowed to flower. Many seed growers have historically produced Certified seed.

3.5.1 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impacts regarding feral alfalfa because no RRA hay or seed would be produced commercially.

Alternative 2: Partial Deregulation of RRA

Based on the above discussions, Alternative 2 would be expected to result in minimal impact to feral alfalfa for the following reasons:

- The reproductive biology of the alfalfa plant combined with normal harvest management for alfalfa forage provide for a de minimis likelihood of gene flow from an RRA forage production fields to feral alfalfa and from feral alfalfa to conventional or organic forage production fields.
- The proposed limitations on the scope of allowed RRA seed production will be defined and stringently controlled as a means to mitigate the likelihood and possible extent of gene flow to non-RRA crops. The proposed restrictions have been designed to enable coexistence by mitigating all or nearly all unwanted gene flow between dissimilar crops and to aid in protecting non-GT, export, and organic hay and seed alfalfa crops. The restrictions include but are not limited to the following: isolation distance, seed field reporting, labeling, segregation and all other contractually required components of the NAFA BMP. All RRA seed acres will be grown under FGI contracts that require each field to be grown and inspected to meet State Seed Certification requirements including the requirement to isolate the field from other alfalfa within 165 ft.; this, therefore, includes control of feral alfalfa. These mitigation measures are practicable, contract-enforced, science-based, and market-driven. There have been negligible impacts since commercial seed production of RRA began in 2005 in large part due to the demonstrated efficacy of these BMP (NAFA, 2009; Fitzpatrick and Lowry, 2010 attached as Appendix K).
- The conservative measures associated with this alternative include additional conservative seed production and forage/hay production restrictions that will ensure an extremely low likelihood and extent of gene flow from one production field to feral alfalfa from feral alfalfa to conventional or organic forage production fields.

3.6 IMPACTS FROM RRA FORAGE CROPS TO RANGELAND ALFALFA CROPS

Commercially cultivated alfalfa and feral alfalfa populations properly belong to the *M. sativa* complex, a group of closely related subspecies that are reproductively compatible. The most commonly cultivated alfalfa in the world is *M. sativa* subsp. *sativa*, but subspecies *falcata* is also cultivated on a limited basis, primarily under rangeland conditions and in colder regions (USDA APHIS, 2009, p. 30).

Rangeland alfalfa populations might increase if certain ranchers intentionally seed alfalfa to increase hay quality and soil nitrogen (Waggener, 2007; High Plains Midwest Ag Journal, 2008). As has historically been the case, seed producers will remain aware of seeding practices in neighboring rangelands, ditchbanks, pastures, roadsides, or other minimally-managed areas.

Both subspecies *M. sativa* subsp. *sativa* and M. s. subsp. *falcata*, have been historically used to derive alfalfa cultivars in North America. In addition to *M. s.* subsp. *sativa* (purple flowered alfalfa), *M. s.* subsp. *falcata* has been used as a winterhardy germplasm source by alfalfa breeders since at least the early 1950s. Therefore, the potential for natural gene flow between subspecies *sativa* and *falcata* is well documented and well understood (Monsanto-FGI comment to the DEIS Appendix 1 p. 14). It is reasonable to predict that hybridization between rangeland *falcata* subspecies and RRA varieties with mostly *sativa* parentage would occur, but they would present no novel or unstudied risk. The limited number of acres of falcata and the barriers for gene outflow from cultivated hay field sources (Putnam, 2006; Van Deynze et al., 2008) will limit the likelihood and extent of effective gene flow from RRA forage production to any synchronous alfalfa plants naturalized in the rangeland. Additionally, gene flow from a naturalized *falcata x sativa* plant to neighboring conventional or organic forage or production fields would be limited by the expected very low frequency of RRA varieties in rangeland usage and the array of gene flow barriers described in Van Deynze et al. (2008).

3.6.1 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impacts to rangeland alfalfa because no RRA hay or seed would be produced commercially.

Alternative 2: Partial Deregulation of RRA

Based on the above discussions, Alternative 2 would be expected to result in minimal impact to rangeland alfalfa for the following reasons:

- The reproductive biology of the alfalfa plant combined with normal harvest management for alfalfa forage provide for a de minimis likelihood of gene flow from one forage production field to another.
- Gene flow mitigation measures (MT/SA, FGI Stewardship Program, and NAFA BMP for RRA Seed Production) are contractually required for all RRA seed producers. These mitigation measures are practicable, contract-enforced, science-based, and market-driven. They have been designed to enable coexistence by mitigating all or nearly all unwanted gene flow between dissimilar crops and to aid in protecting non-GT, export, and organic hay and seed alfalfa crops. There have been negligible impacts since commercial seed production began in 2005 due to the efficacy of these BMP (NAFA, 2009; Fitzpatrick and Lowry, 2010).
- Glyphosate is minimally used in rangeland situations, and therefore there would be no selective advantage for RRA plants in the rangeland. (USDA APHIS, 2009, p. 98-99).
- The conservative measures associated with this alternative include additional conservative seed production and forage/hay production restrictions that will ensure an extremely low likelihood and extent of gene flow from one production field to another.
- As discussed in Section 3.8.1, conventional and organic alfalfa seed will continue to be available.

3.7 IMPACTS FROM RRA FORAGE CROPS TO CONVENTIONAL OR ORGANIC ALFALFA SEED PRODUCTION AREAS

There is potential for cross-pollination due to synchronous flowering in a RRA forage crops and adjacent non-RRA seed crops. As seed producers follow AOSCA isolation distances for seed certification, gene flow will be minimized because gene flow decreases exponentially with distance from crop (Van Deynze et al., 2008) (see also discussion in Section 2.3). Research from Teuber et al. (2007) showed that hay-to-seed gene flow is low if the AOSCA certified seed isolation distance of 165 ft from sexually compatible crops is observed. In that study, at a distance of 165 ft, the extent of gene flow to nearby seed fields was less than 0.5 percent even when neighboring alfalfa hay fields were harvested at 20 or 50 percent bloom. (Hay fields are typically harvested before 10 percent bloom.) When the isolation distance from the edge of the seed crop to neighboring alfalfa forage fields was increased to 350-600 ft, the gene flow decreased to a mean of 0.01 percent (Van Deynze et al., 2008).

3.7.1 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impacts from RRA forage crops to conventional or organic seed production crops because no RRA hay or seed would be produced commercially.

Alternative 2: Partial Deregulation of RRA

Based on the above discussions, Alternative 2 would be expected to result in minimal impact from RRA forage crops to conventional and organic seed production areas the following reasons:

- Alfalfa forage production fields are generally cut prior to 10 percent bloom and before seed is allowed to set.
- Gene flow mitigation measures (MT/SA and Technology Use Guide) are contractually required for all RRA hay producers. These mitigation measures are practicable, contract-enforced, science-based and market-driven. They have been designed to enable coexistence by mitigating all or nearly all unwanted gene flow between dissimilar crops and to aid in protecting non-GT, export, and organic hay and seed alfalfa crops. There have been negligible impacts since commercial seed production began in 2005 due to the efficacy of these BMP.
- Under Restriction Enhancement A of the proposed measures, in states where alfalfa seed production fields were historically (2007) or are currently present, if the RRA forage field is located within 165 ft of a commercial, conventional, seed production field, the RRA grower must harvest forage before 10 percent bloom. This restriction is the science- and market-based, industry recognized isolation distance for certified alfalfa seed crops, and the potential and extent of gene flow of 10 percent bloom hay to nearby seed crops is de minimis at a distance of 165 ft (Teuber and Fitzpatrick, 2007; Van Deynze et al., 2008).
- Additionally, in states where there is more than 100,000 lbs. of annual alfalfa seed production, additional restrictions apply by county to further reduce the potential for gene flow. In counties without seed production, RRA forage growers must report the GPS location of all RRA fields. Under Restriction Enhancement C, in counties with seed production, no new RRA forage plantings are allowed.

- As discussed in Section 3.8.1, conventional and organic alfalfa seed will continue to be available.

3.8 IMPACTS FROM RRA SEED PRODUCTION

3.8.1 Cross-pollination

The greatest potential for cross-pollination and mixing among crop species occurs in seed production because that is where pollination is intended to, and does, occur (see description in Section 2.1.2). The relationships between isolation distance, pollinator species and pollen-mediated gene flow in alfalfa seed production has been studied extensively (Van Deynze et al, 2008). This science informed the current industry standards for isolation in NAFA Best Practices for RRA Seed Production (www.alfalfa.org) and was validated in 2008 and 2009 in large scale surveys of adventitious presence of the RRA trait in conventional seed (Fitzpatrick and Lowry, 2010). Physical mixing of seeds can occur during harvesting, seed cleaning, packaging, and transport. These activities are also governed by NAFA Best Practices for RRA Seed Production, and are components of adventitious presence evaluated in the annual third party audit/validation conducted on commercial seed lots.

The production of non-RRA alfalfa seed and forage both rely on continued availability of non-RRA parent seed, with non-detectable levels of the RRA trait. There is a clear consensus in the industry that there will always be a market (domestic and international) for non-RRA varieties developed and produced in the U.S. There is no reason to believe that industry and/or university alfalfa breeders will not continue to develop varieties for these markets. The production of Breeder seed generation (Syn1) alfalfa seedstock is often done in a screen cage to exclude incoming pollinators, so there should be no new incremental effort required to avoid low level gene flow from neighboring RRA seed or hay production. The production of Foundation (Syn2) alfalfa seedstock requires adherence to AOSCA standards, which include extraordinary isolation from all neighboring alfalfa (seed, hay or uncultivated sources). The standard Foundation seed required isolation of 900 ft is often sufficient to eliminate gene flow from neighboring RRA alfalfa seed or hay production, but occasionally very low levels of adventitious presence are found. When a non-detect standard for Foundation seed is adopted by the breeder, use of an additional isolation distance would decrease the risk of low level gene flow. As a general practice of stringent quality control, Breeder and Foundation seed is routinely evaluated for trueness-to-type, including a lack of off-types. In the event of a low incidence of an off-type, such as presence of the RRA trait in conventional alfalfa, breeders routinely cull the off-type plants and repeat the variety seed increase (APHIS, 2009, Appendix V). Adherence to

AOSCA standards for certified seed production and attention to detail in quality control of seedstocks has been a successful strategy for high quality U.S. seed production by American seed companies (Monsanto/FGI Comments to draft EIS at p. 6-7). Additionally, in cooperation with several U.S. alfalfa seed companies, AOSCA (2010) has developed a new seed production protocol for the production of alfalfa seed. The new protocol is tailored to meet the needs of seeds destined for export, organic and other sensitive market channels where biotechnology traits are expressly excluded. Meeting the specific and incremental requirements of this "special" AOSCA certification program allows the seed producer to label the seed with a statement certifying adherence to the AOSCA program (Monsanto/FGI Comments to draft EIS at p. 5; NAFA, 2008b; NAFA, 2008c; NAFA, 2008d).

3.8.2 Seed Mixing

The biology, cultivation and marketing practices typically used in conventional alfalfa seed and hay production limit the potential for physical and or handling mixtures to very low levels. The likelihood and extent of RRA and non-RRA mixtures are negligible and highly constrained by RRA seed grower practices stipulated and enforced under RRA seed grower contracts. Organic or other GE sensitive hay producers will opt to plant non-GE seeds and will follow their routines for maintaining segregation between hay lots. The impacts to non-RRA markets are expected to be negligible, especially because all RRA seed and hay growers must manage their crop according to their obligations under contracts, licensing, seed certification standards and or segregation standards for organic crops.

RRA is compositionally similar to seed and forage from conventional alfalfa. Therefore, from a food and or feed safety perspective, the impact of mixtures between RRA and non-RRA seeds or forage is negligible. However, as discussed elsewhere in this document (Sections 3.3.4, 3.3.5, 3.15 and 4.10) and extensively throughout the DEIS (USDA APHIS, 2009), there is a segment of consumers and markets that due to their rejection of GE crops or traces thereof, may experience socio-economic concerns and nominal (and voluntary) GE mitigation/avoidence costs (e.g., testing costs).

3.8.3 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impact from RRA seed production on organic or conventional alfalfa seed production because no RRA hay or seed would be produced commercially.

Alternative 2: Partial Deregulation of RRA

Under the partial deregulation alternative, there would be no or negligible impacts to growers of organic or conventional alfalfa seed for the following reasons:

- Gene flow mitigation measures (FGI Stewardship Program, and NAFA BMP for RRA Seed Production) are contractually required for all RRA seed producers. The isolation distances and other mitigation measures required by the NAFA BMP are practicable, contract-enforced, science-based and market-driven. They have been designed to enable coexistence by mitigating all or nearly all unwanted gene flow between dissimilar crops and to aid in protecting non-GT, export, and organic hay and seed alfalfa crops. There have been negligible impacts since commercial seed production began in 2005 due to the efficacy of these BMP. The eight RRA seed grower consortia authorized to plant under partial deregulation would meet or exceed the NAFA BMP parameters with enhanced additional isolation requirements. The minimum required isolation from conventional, commercial seed fields will be 4 miles and 1 mile when honeybees or leafcutter bees are the managed pollinating species, respectively. The potential for gene flow at the NAFA BMP isolation is de minimis (Van Deynze et al., 2008), and the proposed increase to the isolation requirement would further ensure de minimis gene flow potential from RRA seed fields to conventional seed crops should they be present.
- The biology, cultivation and marketing practices typically used in conventional alfalfa seed production limit the potential for physical and handling mixture to very low levels. The likelihood and extent of RRA and non-RRA mixtures are highly constrained by RRA seed grower practices stipulated and enforced under RRA seed grower contracts.
- Conventional and organic alfalfa seed will continue to be readily available to growers.

3.9 LIVESTOCK PRODUCTION SYSTEMS

RRA alfalfa will be used in livestock production systems as feed for livestock. Therefore, its only potential impacts to livestock production systems would be related to animal feed, which is discussed in Section 3.10.

3.10 FOOD AND FEED

Both food (sprouts, dietary supplements, and herbal or homeopathic medicine) and animal feed (hay, haylage, or silage) are derived from alfalfa. In this section we summarize the large body of scientific evidence that has been developed that supports the conclusion that food and feed

derived from RRA are as safe and healthy as food and feed derived from conventional alfalfa. While the evidence has largely been developed by Monsanto and/or FGI, it has been evaluated and peer reviewed by FDA and by panels of government scientists from Canada, Japan, Australia, New Zealand, Mexico, Korea, and the Philippines, all of whom have approved, or recommended for approval, the use of products from RRA in their countries.

We begin with a summary of FDA's authority and policy under the FFDCA with regard to ensuring the safety of food and feed derived from genetic engineering, documenting each element FDA evaluated in its consultation process. We then summarize the evaluations and conclusions of several other international scientific oversight groups.

3.10.1 FDA authority and policy

FDA policy statement. In 1992, the FDA issued a policy statement clarifying its interpretation of the FFDCA regarding foods (including animal feed) derived from new plant varieties, including plants developed by genetic engineering. The purpose of the policy is "to ensure that relevant scientific, safety, and regulatory issues are resolved prior to the introduction of such products into the marketplace" (FDA, 1992). FDA is the "primary federal agency responsible for ensuring the safety of commercial food and food additives, except meat and poultry products" and "FDA has ample authority under the FFDCA safety provisions to regulate and ensure the safety of foods derived from new plant varieties, including plants developed by new techniques. This includes authority to require, where necessary, a premarket safety review by FDA prior to marketing of the food" (FDA, 1992). Under section 402(a)(1) of the FFDCA, a food is adulterated and thus unlawful "if it bears or contains an added poisonous or deleterious substance that may render the food injurious to health or a naturally occurring substance that is ordinarily injurious" (FDA, 1992).

FDA has the authority to ensure safety of new foods. FDA considers its existing statutory authority under the FFDCA and its implementing regulations "to be fully adequate to ensure the safety of new food ingredients and foods derived from new varieties of plants, regardless of the process by which such foods and ingredients are produced" (FDA, 1992). "The existing tools provide this assurance because they impose a clear legal duty on producers to assure the safety of foods they offer to consumers; this legal duty is backed up by strong enforcement powers; and FDA has authority to require premarket review and approval in cases where such review is required to protect public health" (FDA, 1992).

Developers have the responsibility to evaluate the safety of new foods. "It is the responsibility of the producer of a new food to evaluate the safety of the food and assure that the safety requirement of section 402(a)(1) of the act is met. FDA provides guidance to the industry regarding prudent, scientific approaches to evaluating the safety of foods derived from new plant varieties, including the safety of the added substances that are subject to section 402(a)(1) of the act. FDA encourages informal consultation between producers and FDA scientists to ensure that safety concerns are resolved" (FDA, 1992).

Foods developed by new methods do not present greater safety concerns. "FDA believes that the new techniques are extensions at the molecular level of traditional methods and will be used to achieve the same goals as pursued with traditional plant breeding. The agency is not aware of any information showing that foods derived by these new methods differ from other foods in any meaningful or uniform way, or that, as a class, foods developed by the new techniques present any different or greater safety concern than foods developed by traditional plant breeding" (FDA, 1992).

FDA's goal is to ensure the safety of all food and feed. "The goal of the FDA's evaluation of information on new plant varieties provided by developers during the consultation process is to ensure that human food and animal feed safety issues or other regulatory issues (e.g. labeling) are resolved prior to commercial distribution" (FDA, 1997).

3.10.2 FDA biotechnology consultation note to the file BNF 000084

FDA makes the contents of its biotechnology notification files (BNFs) available on the internet (see reference FDA, 2004; RRA is BNF 000084). FDA documented its RRA consultation with Monsanto/FGI in a note to the file dated December 8, 2004 (FDA, 2004). That information is summarized below.

Characterization, inheritance, and stability of the introduced DNA

Using standard analytical techniques, Monsanto/FGI verified that events J101/J163 contained a single copy of the CP4 EPSPS cassette, and that all components were intact (FDA, 2004; Rogan and Fitzpatrick, 2004).

Monsanto/FGI conducted crosses using conventional breeding techniques. These studies indicate that the introduced trait (glyphosate tolerance) was stably inherited as a dominant trait (FDA, 2004; Rogan and Fitzpatrick, 2004).

Using standard analytical techniques, Monsanto/FGI demonstrated the stable integration of the T-DNA over five generations (Rogan and Fitzpatrick, 2004).

Introduced substance – CP4 EPSPS enzyme

As discussed in Section 3.1.1, EPSPS is a catalyst for a reaction necessary for the production of certain aromatic amino acids essential for plant growth and has a similar function in bacteria and fungi (for example, baker's yeast). While EPSPS is present in plants, bacteria and fungi, it is not present in animals; animals do not make their own aromatic amino acids, but rather obtain them from the foods they consume. Thus, EPSPS is normally present in food and feeds derived from plant and microbial sources (Harrison et al., 1996). There are variations in the genetic makeup (amino acid sequences) of EPSPS among different plants and bacteria. The EPSPS used in Agrobacterium sp. strain CP4 is just one variant of EPSPS. A unique characteristic of CP4 EPSPS is that, unlike EPSPS commonly found in plants, it retains its catalytic activity in the presence of glyphosate (FDA, 2004; Rogan and Fitzpatrick, 2004).

Concentrations in alfalfa. CP4 EPSPS protein levels in sample extracts were measured using standard methods, with the resulting average concentration of approximately 0.02 to 0.03 percent (192 to 317 parts per million) (Rogan and Fitzpatrick, 2004).

Toxicity of CP4 EPSPS. The FDA concluded that "the CP4 EPSPS protein produced by RRA lines J101/J163 was biochemically and functionally equivalent to CP4 EPSPSs produced by other RR crops, and to the family of EPSPS proteins that naturally occur in crops and microbiologically-based processing agents that have a long history of safe consumption by humans and animals" (Hendrickson and Price, 2004). This similarity of the CP4 EPSPS protein to EPSPS's in a variety of foods supports the lack of health concerns and extensive human and animal consumption of the family of EPSPS proteins (Rogan and Fitzpatrick, 2004).

Studies were conducted on mice, using CP4 EPSPS doses of 400, 100, and 40 milligrams (mg) of CP4 EPSPS per kilogram (kg) of body weight per day (mg/kg body wt –d). For a typical 0.03-kg mouse, the 400 mg/kg body wt –d dose equated to 12 mg per mouse per day. The study was designed to reflect a 1,000-fold factor of safety on the highest possible human exposure to CP4 EPSPS, based on assumed exposures to soybean, potato, tomato, and corn at the time the study was done (Harrison et al., 1996). The daily CP4 EPSPS content in the maximum mouse exposure was equivalent to the amount in approximately 160 pounds of RRA. No treatment-related adverse effects were observed, and there were no significant difference in any

measured endpoints between the CP4 EPSPS treated mice and the control group (Harrison et al., 1996, p. 735).

Monsanto/FGI also compared the amino acid sequence of CP4 EPSPS to protein sequences in the public domain ALLPEPTIDES database using the FASTA algorithm, and reported no biologically relevant sequence similarities between CP4 EPSPS protein and known toxins were observed (Bonnette, 2004). A peptide is a molecule consisting of several linked amino acids (GMO Safety, 2010a).

Allergenicity. Allergens can be derived from many sources: in animal hair, pollen, insect bites, dust mites, plants, pharmaceuticals, and food. Approximately 20,000 allergens have been identified. Most allergens in food are high molecular weight proteins and are rather resistant to gastric acid and digestive enzymes (GMO Safety, 2010a).

Monsanto searched a comprehensive database of allergens (Hileman et al., 2002) containing sequences of known allergens, for amino acid homology to the CP4 EPSPS protein, and concluded that there was no immunologically significant amino acid sequence homology between the CP4 EPSPS protein and amino acid sequences of allergens in the database (Bonnette, 2004).

At least two studies have been conducted on the mammalian digestibility of CP4 EPSPS. In the first study, the CP4 EPSPS protein was exposed to simulated gastric (stomach) and intestinal fluids that were prepared according to the U.S. Pharmacopoeia (1990). The half-life of the CP4 EPSPS protein was reported to be less than 15 seconds in the gastric fluid, greatly minimizing any potential for the protein to be absorbed in the intestine. The half-life was less than ten minutes in the intestinal fluid (Harrison et al., 1996, p 738). The second study reported similar results (Bonnette, 2004). Specifically, FDA (2004) noted the following from the Monsanto/FGI submmittal: the soil bacterium used to create RRA is not a known allergen or pathogen (does not cause allergic reactions or diseases); the CP4 EPSPS gene and protein lack structural similarities to any allergen (it does not have the same structure as anything that causes allergic reactions).

Food and feed uses of alfalfa

Alfalfa has a long history as a feed source for animals. Greater than 95 percent of alfalfa is used as animal feed.

Human food uses of alfalfa are minor and it is consumed as compressed leaf material for dietary supplements and herbal teas or as fresh sprouts. The seeds germinated for sprouts are

produced and marketed in a distinct, food-grade channel from those for field (non-food) purposes (Section 2.7). A small fraction of alfalfa seeds are used to produce sprouts for human consumption. Any alfalfa seed for sprouts must be certified as having been produced to food-grade specifications and therefore food-grade seed is grown and distributed in an entirely separate channel from that for general use, non-food-grade planting seeds. Food-grade seeds for sprouts are produced throughout the world, but the major suppliers are Canada, Italy, U.S. and Australia. Sprouts are cultivated from clean raw (non-coated, untreated) seeds in controlled environment sprouting chambers for approximately 5 to 10 days before sale to consumers.

FDA and equivalent regulatory bodies in Japan, Korea, Canada, Australia/New Zealand, etc., have granted full approval for the use of RRA as a food (see Section 3.11). Monsanto and FGI have developed the RRA varieties for field planting purposes (only), and as such the companies do not intend nor allow (give license to) any seed growers or seed purchasers to use RRA varieties for food-grade sprout production (Hubbard, 2008; USDA APHIS, 2009, p. 18). The FGI mandated purple seed coating for all commercial RRA seed helps mitigate unintended use of RRA seed for sprouts.

Alfalfa is the principal forage for cattle and horses because of its high nutritional content. The nutritional content of alfalfa is highest in young vegetative alfalfa plants and decreases as plants approach full flower. Dairy cows are generally fed the highest quality alfalfa hay (vegetative to bud stage). Beef cattle, horses, heifers, and non-lactating dairy cows are fed hay that is higher in fiber and lower in protein. Forms of storage include hay, haylage, and silage. Grazing is sometimes used as an alternative to harvesting alfalfa. However, grazing presents a risk of animal loss due to bloating and difficulties in alfalfa stand maintenance if grazing is continuous (Rogan and Fitzpatrick, 2004).

Honey bee hives commonly use alfalfa and clover as nectar sources. Therefore, managed and wild bee hives are often associated with alfalfa fields (FDA, 2004; USDA, 2009 draft EIS Appendix O).

Compositional analysis

To assess whether alfalfa events J101/J163 are as safe and nutritious as conventional alfalfa varieties, the composition of forage produced by Roundup Ready alfalfa plants containing either event J101, J163, or the paired events J101 X J163 was measured and compared to the composition of control and conventional alfalfa forage. This study was conducted under USDA

Notification Number 01-029-12n. Forage was harvested from plants grown in field trials and analyzed using standard methods or other suitable methods (Monsanto, 2004).

Forage samples were collected from all plots and analyzed for 35 different nutritional components. Compositional analyses of the forage samples included proximates (protein, fat, ash and moisture), acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin, amino acids, and minerals (calcium, copper, iron, magnesium, manganese, phosphorous, potassium, sodium and zinc), as well as carbohydrates by calculation. In all, 35 different components were analyzed to assess the composition of Roundup Ready alfalfa (Rogan and Fitzpatrick, 2004).

Statistical analyses were performed on the compositional data for the RRA containing events J101/J163. As expected, statistically significant differences were observed for the concentration of some of the analytes in comparison to the control. Where values were different, the mean was within the 99 percent tolerance interval developed for the analyte using conventional alfalfa reference varieties. Therefore, it is unlikely that these differences are biologically meaningful. These data are consistent with the conclusion that forage produced by alfalfa plants containing event J101 or J163 is comparable to forage produced by control or conventional alfalfa varieties. These compositional data support the conclusions derived from other phenotypic studies indicating that no biologically meaningful changes were associated with alfalfa populations containing event J101 or event J163 (Monsanto, 2004).

Conclusion

Based on the data submitted, the FDA considered the consultation process to be complete and acknowledged this in Biotechnology Consultation Note to the File BNF No. 000084 (FDA, 2004).

3.10.3 Health Canada approval 2005

Health Canada's Food Directorate has legislated responsibility for premarket assessment of "novel foods." Under Canadian regulations, foods derived from alfalfa lines containing events J101/J163 are considered novel foods because they are derived from a plant that has been GM to exhibit characteristics that were not previously observed in the plant (Health Canada, 2005).

Health Canada conducted a comprehensive assessment of GT alfalfa lines containing events J101/J163 according to its "Guidelines for the Safety Assessment of Novel Foods," reviewing the same information Monsanto/FGI provided to FDA in its consultation, and made the following conclusion (Health Canada, 2005):

> "Health Canada's review of the information presented in support of the food use of glyphosate tolerant alfalfa lines containing events J101/J163 concluded that

the food use of alfalfa lines containing this event does not raise concerns related to safety. Health Canada is of the opinion that alfalfa lines containing events J101/J163 are as safe and nutritious as current commercial alfalfa varieties."

3.10.4 CFIA approval 2005

The CFIA evaluated GT alfalfa events J101/J163 for use as livestock feed and approved their use in 2005. Based on its evaluation of data provided by Monsanto/FGI, and as summarized in its Decision Document DD2005-53, the CFIA "determined that these plants with a novel trait (PNT) do not present altered environmental risk nor, as a novel feed, do they present livestock feed safety concerns when compared to currently commercialized alfalfa varieties in Canada" (CFIA, 2005).

3.10.5 Japan approval

Japan approved the food use RRA in 2005 and the feed use in 2006. Environmental approval was also granted in Japan in 2006 (Japan Biosafety Clearinghouse, 2010; Center for Environmental Risk Assessment, 2010).

3.10.6 Australia – New Zealand approval

Food Standards Australia New Zealand (FSANZ) is a bi-national government agency with responsibility to develop and administer the Australia New Zealand Food Standards Code. FSANZ approved the food use of RRA in 2006 (FSANZ, 2006). FSANZ found "no public health and safety concerns. On the basis of the available evidence, including detailed studies provided by the Applicant, food derived from GT lucerne J101/J163 is considered as safe and wholesome as food derived from other commercial lucerne varieties." (FSANZ, 2006, p. ii).

3.10.7 Other approvals

RRA was also approved for use as food and/or feed in Mexico in 2005 (Ministry of Health), in the Philippines in 2006 (Department of Agriculture Bureau of Plant Industry), and in Korea in October 2007 (Center for Environmental Risk Assessment, 2010). Environmental approval was granted in Korea in January 2008 (Rural Development Administration).

3.10.8 Impacts

Alternative 1: No Action

Under Alternative 1, there would be no impact from RRA on feed or food, or on consumer choice.

Alternative 2: Partial Deregulation of RRA

Health effects of consumption of RRA. Alfalfa is consumed as both animal feed (hay/haylage) and human food (e.g., alfalfa sprouts). Based on the scientific evidence summarized in this section, health impacts from consuming RRA food or feed are not expected from RRA. Feed derived from RRA is equivalent to feed derived from conventional alfalfa. Although RRA has been found to be equivalent to conventional alfalfa by several international scientific agencies, Monsanto/FGI have determined that RRA will not be licensed for use for any human food purposes.

Health and consumer choice effects of consumption of food or feed derived from RRA. Beef and dairy products may be derived from cattle/cows that have consumed RRA. The Food and Agricultural Organization of the United Nations (FAO), the World Health Organization (WHO), and the Organization for Economic Cooperation and Development (OECD) have made statements regarding the potential for the protein encoded by the transgene (the CP4 EPSPS protein) to transfer to animal-derived products intended for human consumption (FAO/WHO 1991; FDA 1992; OECD 2003). These reports, as well as the studies summarized above in this section have concluded that the CP4 EPSPS protein is equivalent to other forms of the EPSPS protein, and that food and feed containing the CP4 EPSPS protein is as safe and nutritious as the conventional counterparts. As discussed in Section 3.10.1, the half-life of the CP4 EPSPS protein in the digestive system is only a few minutes; no detectable amounts of the CP4 EPSPS protein are expected to be found in beef or dairy products from animals fed RR alfalfa. Although uncommon, fragments of transgenes have been found in dairy and animal products (Flachowsky and others, 2005). If very low levels of transgenic fragments could be infrequently found in dairy products and beef from cattle/cows consuming RRA, presumably they would also be present in the same products, from the use of corn as cattle feed, as most corn grown in the U.S. is genetically engineered. Honey from bees is mostly fructose and glucose; however, possibly it could have minute fragments of transgenic DNA from pollen from RRA. The presence of DNA fragments, GE or otherwise, is not a health issue (on the safety of DNA (FDA, 1992); however, depending on how "non-GE food" is defined, it could affect a consumer's choice to consume non-GE food. The minute levels that might potentially be found in honey, beef or dairy products would, for example, be far below the threshold standards for non-GE food proposed by the Non-GMO Project (Section 1.5). A consumer with "zero tolerance" for beef or dairy derived from GE products or that might contain minute fragments of transgenes would have the choice of consuming organic honey, beef and dairy products. Presumably that

consumer would already be consuming organic beef and dairy products because of the use of GE corn as cattle feed. Market demand will ensure that conventional and organic alfalfa will still be available to the dairy or cattle farmer who wishes to avoid RRA.

Summary. Based on the above analysis, Alternative 2 would be expected to have no or negligible impacts on food or feed, or consumer choices regarding food or feed.

3.11 WEED CONTROL AND GR

3.11.1 Weed control with conventional alfalfa

Weed management is an important aspect of alfalfa production. Some of the negative effects of weeds in alfalfa crops include the following:

- competition with weeds can reduce yield and cause thinning in the stand;
- weeds can lower the nutritional quality of alfalfa hay because many weeds are lower in protein (50 percent less protein than alfalfa) and higher in fiber compared to alfalfa;
- poisonous weeds containing toxic alkaloids (a type of chemical) (e.g., common groundsel, fiddleneck, yellow starthistle, and poison hemlock) can make alfalfa hay unmarketable;
- under some conditions weeds can accumulate toxic nitrate concentrations (e.g., lambsquarters, kochia, and pigweed);
- some weeds with a spiny texture can cause mouth and throat ulcerations in livestock (e.g., foxtail, wild barley, cheatgrass, and bristlegrass);
- weeds that are unpalatable to livestock result in less feeding and, therefore, less productivity (of either beef or milk);
- some weeds can contribute to off flavors in milk (e.g., wild celery, Mexican tea, creeping swinegrass, and mustards); and
- weeds that contain higher moisture content than alfalfa (e.g., dandelion) can cause bale problems such as mold, off-color hay, and high bale temperatures, which are a fire hazard.

(Canevari et al., 2007; Canevari et al., 2006; Van Deynze et al., 2004; Loux et al., 2007; Miller et al., 2006; Orloff et al., 1997; Orloff et al., 2009, attached as Appendix D; USDA APHIS, 2009 pp. 105-06).

Without weeds, alfalfa can grow at a density of about 12 plants per square foot. Heavily weed-infested stands can have less than one alfalfa plant per square foot (Canevari et al., 2007). In California, if weeds are not effectively controlled, they can represent up to 76 percent of the first cutting yields (USDA APHIS, 2009, p. 106).

3.11.2 Weed control with RRA

The following discussion of RRA and weed management was based largely on the technical report, *Effects of Glyphosate-Resistant Weeds in Agricultural Systems* (USDA APHIS 2009, Appendix G, attached as Appendix E of this ER).

RRA can be used by farmers for weed management in alfalfa crops. Its unique characteristics allow for effective weed control throughout the growing season of an alfalfa crop, and, alfalfa and alfalfa farming practices per se have characteristics that will complement the weed control provided by glyphosate and, as such, will aid in the suppression of the development of GR weeds. The ability for alfalfa to fix nitrogen encourages the decision to follow alfalfa in the rotation with a crop that requires additional nitrogen, such as the annual grasses of corn and various cereal crops. These subsequently rotated crops can tolerate a spectrum of herbicides substantially different from the herbicides used in alfalfa. This encourages rotation of crops and herbicides, both of which are highly recommended for reducing the probability of developing herbicide resistant weeds (Orloff et al., 2009; USDA APHIS, 2009, p. 109).

Alfalfa produced for forage purposes (e.g., hay and silage in GE, conventional, or organic production systems) is mowed regularly at a recommended cutting height of 3 inches. This removes all plant material higher than 3 inches including weeds (Orloff et al., 1997), which may not have had time to produce flowers, pollen or seed. This regular removal of all plant mass above 3 in. of the soil surface, including all vegetative weed material, greatly suppresses or eliminates seed production in weed species, and is especially effective in controlling annual weeds (USDA APHIS, 2009, p. 109).

In a RRA farming system for forage, the combination of broad spectrum weed control from glyphosate (which should lead to more vigorous alfalfa competition), and regular mowing, which reduces the likelihood that any GR weeds in the RRA field have had time to produce pollen or set seed, greatly decreases the probability of the development of GR weeds. In some parts of the western U.S., alfalfa produced with irrigation requires multiple herbicide applications to control repeated influx of weed seed introduced with irrigation water. In most cases the use of one or more non-glyphosate herbicides with increased residual activity will be required to

provide effective weed control (Orloff et al., 2009, attached as Appendix D). In seed production, although an early spring or late fall mowing sometimes occurs, in-season mowing only occurs once, as one seed crop is removed each year; thus, there is a potential for greater weed seed production compared to alfalfa forage production. However, in order to maximize yield for a seed crop and minimize weed seed content, alfalfa seed production (including RRA seed production) currently receives significantly higher cultural and herbicide inputs (beyond glyphosate only) to reduce weed cover than in alfalfa forage production. Glyphosate can only be applied in alfalfa seed production when plants are in the vegetative state. Other herbicides will be used to control weeds during the longest part of the growing season. These additional herbicides with other modes of action will also work to reduce weed seed production and minimize glyphosate-resistant weeds in the seedbank of fields where RRA is grown for seed (USDA APHIS, 2009, p. 109).

3.11.3 Herbicide-resistant weeds

A number of genetic, biological/ecological, and operational factors are involved in determining if a weed species will evolve a resistance to any herbicide (Georghiou and Taylor, 1986; Neve, 2008). Genetic factors include the frequency of genes in a weed species that promotes resistance to a particular herbicide, the ability and rate of changes to genes to cause resistance, the way genes for resistance are passed down to offspring, and the fitness of the plant (and these genes) in the presence and absence of an herbicide. Biological and ecological factors include how the weed species reproduces (selfing or outcrossing), seed production capacity, seed bank turnover, and amount of gene flow within and between populations (Maxwell and Mortimer, 1994; Jasieniuk et al., 1996; Neve, 2008). The genetic factors and biological/ecological factors involved highlight that different species may present different risks of resistance, depending on the genetics of the weed and the biology of the plant. Operational factors involved in the evolution of weed resistance include the type of chemistry and how the herbicide kills plants (e.g. mode-of-action), the frequency with which the herbicide is applied, and the dose and pattern of herbicide application.

Alfalfa weed management, including major weeds in alfalfa, herbicides used, herbicide mode of action, and herbicide resistance, was discussed in Sections 2.5. Measures to reduce herbicide resistance were also discussed in Section 2.5.

3.11.4 GR weeds

As discussed in Section 2, herbicide resistance is not a unique or new phenomenon. The development of weeds resistant to a particular herbicide mode of action is an issue that growers have faced for decades. As with other herbicide modes of action, not all weeds respond the same to glyphosate, and some species naturally vary in their tolerance to the herbicide.

Because of the nature of glyphosate and its history of use, generally speaking, there is a reduced potential that there will be a selection for weed resistance, compared to other herbicides. Glyphosate is a nonselective, foliar-applied, broad spectrum, post-emergent herbicide compared to many other herbicide groups. It operates by binding to a specific enzyme in plants thereby interfering with the plant's required metabolic process. Glyphosate is the only herbicide that binds with this enzyme, and therefore it is highly specific (Cole, 2010, p. 5; Orloff, 2009, p. 6, attached as Appendix D).

Accordingly, while glyphosate has been used extensively for over three decades, there have been relatively few cases of resistance development, as compared to many other herbicides and when considering the substantial glyphosate-treated acreage worldwide (approximately 1 billion acres) and the total number of weeds that the herbicide can control. In the U.S., there are ten weed species where GR biotypes are known to exist in certain areas of the country (19 weeds have been reported to have developed GR at some location worldwide). These resistant weeds represent a relatively small minority of the overall weed population. For example, in 2009, approximately 135 million of the 173 acres of corn, soybeans and cotton in the U.S. were planted with a herbicide tolerant variety, with the most common tolerance trait being glyphosate tolerance (USDA NASS, 2009a). At the same time, only about 6 percent of the total planted corn, soybean and cotton acres in the U.S. are estimated to have some level of presence of weeds resistant to glyphosate (Ian Heap as reported by WSSA, 2010b). As discussed above, the characteristics of glyphosate itself reduce the potential for the development of herbicide resistance as compared to other herbicide families. As such, certain herbicide families have been classified according to their risk of resistant weed development. Beckie (2006) lists ALS and ACCase inhibiting herbicides as "High" risk for resistance development, while glyphosate is considered a "Low" risk herbicide for the development of herbicide resistant weeds. ALS and ACCase inhibiting herbicides are commonly used in conventional alfalfa production, and weeds resistant to these two herbicide groups are widely distributed across alfalfa growing regions of the U.S. RRA can help delay resistance to these herbicides by adding to the diversity of herbicide modes of action in alfalfa production.

Use of herbicides with different modes of action, either concurrently or sequentially, is an important defense against weed resistance (WSSA, 2010b). "Use of a single product or mode of action for weed management is not sustainable. Some of the best and most sustainable approaches to prevent resistance include diversified weed management practices, rotation of modes of action and especially the use of multiple product ingredients with differing modes of action" (WSSA, 2010b). In addition, cultural practices such as cultivation or mowing are effective weed resistance management operations.

The WSSA reports higher levels of awareness among growers regarding the need to minimize the potential for development of GR: "In a market research study that surveyed 350 growers in 2005 and again in 2009, in response to the question, 'are you doing anything to proactively minimize the potential for resistance to glyphosate to develop,' 67 percent said yes in 2005 and 87 percent said yes in 2009" (David Shaw, as reported in WSSA, 2010). "In a 2007 survey of 400 corn, soybean and cotton growers, resistance management programs were often or always used by 70 percent or more of all three grower groups" (Frisvold and Hurley as reported by WSSA, 2010b). There is widespread information available from universities and other sources regarding GR. Public universities (i.e. University of California, North Dakota State University, University of Minnesota), herbicide manufacturers (i.e. www.weedresistancemanagement.com, www.resistancefighter.com) and crop commodity groups (i.e. National Corn Growers Association, American Soybean Association) have internet web sites with information on prevention and management of herbicide resistance. Monsanto's TUG (attached to this document as Appendix A) provides specific management practices for the prevention of glyphosate resistant weeds. Additionally, the UC's Integrated Pest Management website (http://www.ipm.ucdavis.edu/PGM/weeds_common.html) and at the UC Weed Research and Information Website (http://wric.ucdavis.edu/information/information.html) provide information on weed identification and specific weed management practices (Orloff et al., 2009; attached as Appendix D).

Alfalfa growers have strong financial and practical interests in managing weeds effectively and preemptively to reduce the development of herbicide resistance in order to maximize yield potential. The development of GR weeds harms the economic return per acre for the individual farmer and the entire alfalfa industry (Orloff et al., 2009, attached as Appendix D).

As such, strategies and recommendations to delay the development of GR weeds have been developed for alfalfa (Orloff et al., 2009, attached as Appendix D; TUG, attached as Appendix A). In general, weed scientists recommend the following to mitigate the risk of herbicide

resistance in alfalfa: (1) Apply integrated weed management practices. Use multiple herbicide modes-of-action with overlapping weed spectrums in rotation, sequences, or mixtures; (2) Use full recommended rate and proper application timing for the hardest to control weed species present in the field; (3) Scout fields after herbicide application to ensure control has been achieved; (4) Avoid allowing weeds to reproduce by seed or to proliferate vegetatively; (5) Monitor site and clean equipment between sites; (6) Start with a clean field and control weeds early by using a burndown treatment or tillage in combination with a preemergence residual herbicide as appropriate; (7) Use cultural practices such a cultivation and crop rotation, where appropriate; and (7) Use good agronomic principles that enhance crop competitiveness. (HRAC, 2009). Similarly, the TUG recommends scouting for weeds; starting with a clean field using a burndown herbicide application or tillage; controlling weeds when they are small; crop rotation with opportunities for other modes of action; crop rotation; and "the right herbicide product at the right rate and at the right time." (TUG, p. 10, attached as Appendix A). All RR technology users, including alfalfa growers, are contractually obligated through the MT/SA to follow the TUG. RRA seed growers are also required by the NAFA BMP to "[m]anage weeds and volunteers using integrated weed control strategies (e.g., conventional practices supplemented with Roundup agricultural herbicide formulations applied according to the label for alfalfa seed production)" (NAFA, 2008).

Table 2-5 in Section 2.4.2 lists weeds known to be found in alfalfa and the biotypes known to be glyphosate resistant. Since 1998, 14 new GR weeds have been found globally. Nine of these have glyphosate resistant biotypes in the U.S. Of these nine, four species are known to be common in alfalfa fields.

3.11.5 Impacts

Alternative 1: No Action

Under Alternative 1, there would be virtually no effect on the potential for weeds to develop resistance to glyphosate, given that glyphosate use is minimal with conventional alfalfa. However, under Alternative 1, the impact of weeds resistant to other herbicides is likely to continue to increase as growers would continue to use conventional weed control methods, including other herbicide modes of action.

As discussed above, glyphosate use in alfalfa can be an effective tool against weeds resistant to non-glyphosate herbicides, such as ALS-inhibitors and ACCase-inhibitors. Weed resistance

to glyphosate is not as common as resistance to many other herbicides (Orloff et al., 2009, p. 6, attached as Appendix D).

Alternative 2: Partial Deregulation of RRA

Under Alternative 2, impacts, if any, with respect to the development of GR weeds due to increased use of glyphosate associated with RRA crop production are expected to be very small. First, as discussed above, the nature of glyphosate itself makes it less likely that new GR weed populations will develop in alfalfa as a result of the use of glyphosate in RRA. Specifically, there is a relatively low rate of resistance in weeds to glyphosate relate to the widespread use of this chemical. (Orloff et al., 2009, p. 6; attached as Appendix D). Because of this differential in weed resistance between glyphosate and other herbicides, the introduction of this additional mode of weed control may have a net positive effect on weed resistance in alfalfa production. Second, there is a high level of awareness about the potential for GR weeds and many readily available resources to assist growers with management strategies (e.g., Orloff et al., 2009). Third, because herbicide resistance is a heritable trait, it takes multiple growing seasons for herbicide tolerant weeds to emerge and become the predominant biotype in a specific area (Cole, 2010a, p. 4). Researchers have concluded that even if growers completely relied on only one herbicide, it is likely to take at least five years for an herbicide-resistant weed population to develop (Kniss, 2010a, p. 4; Beckie, 2006, Neve, 2008; Werth et al., 2008). This is a reason why crop monitoring and follow up by weed scientists in cases of suspected resistance are important parts of all herbicide resistance stewardship programs. Fourth, RRA growers are required to abide by the following requirements, which will operate to mitigate the risk of glyphosate weed resistance in RRA:

- Read and follow all herbicide use directions and recommendations;
- Follow all stewardship practices outlined in Monsanto's TUG (Appendix A) which includes weed resistance management practices; and
- • Follow the Weed Resistance Management Guidelines to minimize the risk of resistance development (see Monsanto's TUG, p. 4; http://www.weedresistancemanagement.com/guidelines.html).

3.12 PHYSICAL

The assessment of impact to land use in the sections below considers the impacts to land use or current cultivation practices under the no action alternative and the proposed partial deregulation alternative.

3.12.1 Land Use

Alternative 1: No Action

Under Alternative 1, there would be no impact to land use or current cultivation practices. There would be no new planting of RRA for commercial purposes. It is anticipated that existing alfalfa acres would continue to be planted with non-RRA or non-alfalfa crops.

Alternative 2: Partial Deregulation of RRA

Under Alternative 2, it is expected that RRA would be planted on existing alfalfa acreage for hay or seed production provided that the proposed partial deregulation measures discussed in Section 1.1.3 above are followed. Appendix G charts the anticipated adoption of RRA under Alternative 2. However, the impact of this alternative on the overall amount of land devoted to alfalfa cultivation is expected to be minimal, as under this alternative, land currently used for alfalfa seed or hay production would continue to be used in the same manner. Alfalfa production is largely a market-driven decision rather than a technology-driven decision. (USDA-APHIS, 2009, p. 157). The availability of a new weed control option is not expected to impact current land use management. However, since glyphosate controls a broad range of weeds, farmers may choose to plant RRA on fields with greater weed potential. If the life span of RRA can be extended longer than current alfalfa stand lifespans, this might impact land use decisions regarding crop rotation practices, but is not expected to change the nature of land use into or out of agricultural production.

3.12.2 Air Quality and Climate

The assessment of impacts to air quality and climate in the sections below considers impacts to air quality and climate practices under the no action alternative and the proposed partial deregulation alternative. Under Alternative 1, existing alfalfa acreage will continue to be planted with non-RRA or non-alfalfa crops.

Alternative 1: No Action

The no action alternative would result in an adverse impact to air quality and climate. The continued regulation of RRA would result in continued planting of conventional and/or organic alfalfa. Non-RRA requires greater tillage for weed control than does RRA. Weed control in non-RRA is usually primarily accomplished by pre-plant tillage to prepare a weed-free seed bed, and/or by clipping targeted to stop weed growth and competition (with or without crop harvest). As glyphosate is a crop-safe, broad spectrum herbicide, it is possible that additional alfalfa

acres, like other herbicide tolerant crops, would be established using no-till methods. Comparatively, the tillage associated with non-RRA establishment requires greater use of farm machinery which results in greater greenhouse gas emissions.

Alternative 2: Partial Deregulation of RRA

As previously stated, the partial deregulation of RRA is expected to result in an increase in the total acreage of RRA crops. This would be accompanied by increased glyphosate application and decreased tillage of alfalfa fields. Because glyphosate is non-volatile (i.e., does not evaporate readily) at normal temperatures and is not considered an atmospheric contaminant (EPA, 1993), the increased application of glyphosate is not expected to result in adverse impacts to air quality. If glyphosate is applied aerially, any potential drift-related impacts can be minimized by utilizing recognized practices for managing the potential for off target movement (i.e., using of specific nozzle types, limiting applications to conditions less favorable for drift). The overall impacts from aerial application are expected to be minimal because only around two percent of glyphosate is applied aerially in the U.S. (USDA APHIS, 2009). The decreased tillage of alfalfa fields under this alternative would have a net positive effect on air quality and climate by reducing the operation of farm machinery and the associated greenhouse gas emissions. Emissions related to global warming, ozone depletion, summer smog and carcinogenicity, among others, were found to be lower in GT crop systems than conventional systems (Bennett et al., 2004).

3.12.3 Water Quality

The assessment of impacts to water quality in the sections below considers impacts on surface water quality and groundwater. Under Alternative 1, alfalfa acres will continue to be planted with non-RRA or non-alfalfa crops.

Alternative 1: No Action

Surface water. Alternative 1 would have an adverse impact on surface water quality. Under this alternative, growers would continue to plant conventional and organic alfalfa, resulting in the continued reliance on tilling and/or multiple herbicides for weed control. The adverse impact would be due to the continued generation of runoff containing: 1) herbicides with greater environmental impact than glyphosate; and/or 2) particulate matter derived from increased tillage and soil erosion. Tillage causes widespread soil disturbance resulting in erosion and topsoil loss, with a corresponding increase in sedimentation and turbidity in streams. This

erosion can also transport herbicides used on the fields into the surface waters. The usage of a GT cropping system such as RRA allows for cultivation with reduced tillage.

Groundwater. Alternative 1 would result in an adverse impact to groundwater. Adverse impacts would result from the continued use of multiple herbicides to control weeds. The vast majority of growers would continue to plant conventional alfalfa, resulting in the use of multiple herbicides for weed control. Several non-glyphosate herbicides have a higher potential to leach into groundwater, which results in groundwater contamination.

Alternative 2: Partial Deregulation of RRA

Surface water. Partial deregulation would result in increased planting (increased acreage) of RRA. The associated increase in application of glyphosate for weed control would reduce the impact on surface water quality by facilitating the adoption of conservation tillage methods and reducing the use of other herbicides with greater potential for adverse impact. Conservation tillage reduces disturbance of the soil and associated soil erosion from wind and water, and is facilitated by use of a GT cropping system such as RRA. The net effect would be lower amounts of herbicide and suspended sediment in runoff, which would improve water quality in streams and lakes (Wiebe and Gollehon, 2006).

Groundwater. The increased application of glyphosate under Alternative 2 would have a positive effect on groundwater quality by reducing the use of other herbicides that more readily leach into groundwater.

3.13 BIOLOGICAL

Potential environmental effects of pesticide use are carefully considered as a part of the FIFRA pesticide registration process. Prior to the approval of a new pesticide or a new use of that pesticide (including a change in pesticide application rates and/or timing) and before reregistering an existing pesticide, EPA must consider the potential for environmental effects and make a determination that no unreasonable adverse effects to the environment will be caused by the new pesticide, new use or continued use.

To make this determination, EPA requires a comprehensive set of environmental fate and ecotoxicological data on the pesticide's active ingredient (40 C.F.R. Part 158). EPA uses these data to assess the pesticide's potential environmental risk (exposure/hazard). The required data include both short- and long-term hazard data on representative organisms that are used to predict hazards to terrestrial animals (birds, nontarget insects, and mammals), aquatic

animals (freshwater fish and invertebrates, estuarine and marine organisms), and nontarget plants (terrestrial and aquatic).

Information regarding the impacts of glyphosate on the biological environment is summarized below. Additional information on this topic is also being considered in the USDA APHIS Draft Environmental Impact Statement (DEIS) on the Deregulation of Glyphosate Tolerant Alfalfa (Docket No. APHIS-2007-0044) (USDA APHIS, 2009).

3.13.1 Animal and plant exposure to glyphosate

Glyphosate is a non-selective herbicide with post-emergence activity on essentially all annual and perennial plants. As discussed in Section 3.1.1, this activity is due to inhibition of EPSPS, an enzyme involved in aromatic amino acid synthesis. As with any herbicide, a risk exists that spray drift could pose issues for plants on the borders of the target field. However, EPA takes the potential for spray drift into account when conducting the risk assessment it uses to establish pesticide application rates and direction for use, which are designed to minimize spray drift risks. Glyphosate binds tightly to agricultural soils and is not likely to move offsite dissolved in water. Moreover, glyphosate is not readily taken up from agricultural soil by plants. This limits the impact of glyphosate use on non-target plants, including aquatic plants.

Alternative 1: No Action

Plants. Under the no action alternative, RRA would remain regulated, and growers of conventional alfalfa would continue to use multiple herbicides for weed control. Many of the non-glyphosate herbicides are selective herbicides that kill only particular groups of plants such as annual grasses, perennial grasses, or broadleaf weed species. Therefore, growers of conventional alfalfa use more than one herbicide to achieve satisfactory weed control. In addition, some of the other herbicides are applied at greater volumes compared to glyphosate.

The continued use of other herbicides would result in potential adverse impacts to non-target plants. The herbicides used in conventional alfalfa production have been found, in general, to have more significant environmental impacts than glyphosate (USDA APHIS, 2009). This is consistent with the EPA decision to grant reduced risk status for glyphosate use in RRA. Comparison of results from terrestrial and aquatic plant studies with predicted exposure from herbicide use suggests that most of the herbicides used in conventional alfalfa systems may have greater adverse effects than glyphosate on aquatic or terrestrial plant species.

Animals. Under this alternative RRA would remain regulated, and growers of conventional alfalfa would continue to use an array of herbicides for weed control. Many of the herbicides

used in conventional alfalfa production have been found to have higher toxicity to certain animal species than glyphosate. Animal species within and adjacent to fields of conventional alfalfa would continue to be exposed to these more toxic herbicides. The amphibian habitat in watersheds where conventional and organic alfalfa are grown would continue to be impacted by higher levels of tillage, soil erosion, sedimentation in runoff, and turbidity in ponds, lakes, and rivers than would otherwise be the case if RRA were grown.

Under this alternative, alfalfa growers will continue to have difficulty controlling certain weed species that sicken, poison or reduce growth of horses, cattle and other livestock. Livestock illness and suffering related specifically to consumption of toxic weeds in alfalfa forage would remain unchanged. Economic losses associated with veterinary service costs and livestock productivity losses would remain unchanged.

Alternative 2: Partial Deregulation of RRA

Plants. With partial deregulation, the acreage of RRA and the associated use of glyphosate would increase. The increased glyphosate use would be accompanied by a corresponding decrease in the use of other herbicides that have a higher potential to impact non-target plant life. So this alternative would have an overall positive effect on terrestrial and aquatic plants. The EPA has concluded that glyphosate use on RRA poses reduced risk compared to the use of other herbicides for weed control.[43] As is the case with aerial application of any herbicide, terrestrial and aquatic plants in the vicinity of alfalfa fields may be incidentally exposed to glyphosate by spray drift. However, if aerial applications are minimized and/or appropriate spray drift reduction practices are utilized, this risk to non-target plants would be reduced; recall that EPA has determined that no unreasonable adverse effects occur from spray drift of glyphosate when applied according to label directions. Each year there are millions of acres of GT crops that are treated with glyphosate with minimal impact to adjacent non-target terrestrial plants including crops, when appropriate drift minimization measures are practiced.

Because glyphosate binds strongly to soil particles and has no herbicidal activity after binding to soil, no effects on aquatic plants will result from surface water runoff from glyphosate use on RRA. Conservation tillage and no tillage practices have the potential to mitigate impacts to aquatic plants through decreasing soil-laden runoff.

[43] A reduced risk decision is made at the use level based on a comparison between the proposed use of the pesticide and existing alternatives currently registered on that use site. A list of decisions regarding Reduced Risk Status can be found at: http://www.epa.gov/opprd001/workplan/reducedrisk.html

Animals. With partial deregulation, the acreage of RRA and the associated use of glyphosate would increase. The increased glyphosate use would be accompanied by a corresponding decrease in the use of other herbicides that have a higher potential to impact animals.

Based on the data available on glyphosate usage, chemical fate, and toxicity, glyphosate is not expected to pose an acute or chronic risk to the following categories of wildlife (EPA, 1993):

- Birds;
- Mammals;
- Terrestrial Invertebrates;
- Aquatic Invertebrates;
- Fish; and
- Soil Microorganisms.

Glyphosate is practically non-toxic to slightly toxic to birds, freshwater fish, marine and estuarine species, aquatic invertebrates and mammals and practically non-toxic to honey bees (which are used to assess effects on non-target insects in general) (EPA, 1993). Glyphosate has a low octanol-water partition coefficient, indicating that it has a tendency to remain in the water phase rather than move from the water phase into fatty substances. Therefore, it is not expected to accumulate in fish or other animal tissues.

As a part of the reregistration evaluation under FIFRA, EPA conducted an ecological assessment for glyphosate. This assessment compared the results from toxicity tests with glyphosate conducted with various plant and animal species to a conservative estimate of glyphosate exposure in the environment (Estimated Environmental Concentration (EEC)). In the Reregistration Eligibility Decision (RED) for glyphosate (EPA, 1993), the exposure estimates were determined assuming an application rate of 5.0625 lb active ingredient per acre (ai/A), which exceeds 3.75 lb a.e./A, the maximum EPA labelled use rate for a single application for agricultural purposes. When the EECs were calculated for aquatic plants and animals, the direct application of this rate (5.0625 lb a.e./A) to water was assumed. Based on this assessment, EPA concluded that effects to birds, mammals, fish and invertebrates are minimal based on available data (EPA, 1993).

The glyphosate end-use products used in agriculture contain a surfactant to facilitate the uptake of glyphosate into the plant (Ashton and Crafts, 1981). Depending on the surfactant used, the toxicity of the end-use product may range from practically nontoxic to moderately toxic to fish

and aquatic invertebrates (EPA, 1993). For this reason, the 1993 Glyphosate RED stated that some formulated end-use products of glyphosate needed to be labeled as "Toxic to fish" if they were labeled for direct application to water bodies. Due to the associated hazard to fish and other aquatic organisms, glyphosate end-use products that are labeled for applications to water bodies generally do not contain surfactant, or contain a surfactant approved for direct application to water bodies.

Possible adverse impacts to amphibians resulting from the deregulation of RRA may be offset by the shift from other herbicides used in alfalfa cultivation, which are considered to have higher environmental impacts in general. Additionally, amphibian habitat in watersheds where RRA is produced could be improved through conservation tillage, resulting in decreased soil erosion, decreased sedimentation in runoff, and decreased turbidity in ponds, lakes, and rivers fed by surface waters.

Glyphosate can theoretically be toxic to microorganisms because it inhibits the production of aromatic amino acids through the shikimate pathway. However, field studies show that glyphosate has little effect on soil microorganisms, and, in some cases, field studies have shown an increase in microbial activity due to the presence of glyphosate (USDA FS, 2003).

Glyphosate itself is slightly toxic to amphibians; however, amphibians exhibited greater sensitivity to Roundup® formulations than to glyphosate tested as an acid or isopropylamine (IPA) salt. This could be due to the surfactant (POEA) used in agricultural formulations, which has been found to be more toxic to amphibians and other aquatic animals than the herbicide itself (Lajmanovich et al., 2003). Some researchers have suggested that, in combination with POEA, Roundup® could cause extremely high rates of mortality to amphibians that could lead to eventual population declines (Relyea, 2005). However, the testing methods of the Relyea (2005) study have been called into question due to the high exposure doses, which exceed application rates of glyphosate (regulated by FIFRA), as well as the fact that this Roundup® product is not approved for use in an aquatic setting (USDA APHIS, 2009). Considering the potential for aquatic exposure to glyphosate formulations from terrestrial uses, EPA recently evaluated the effect of glyphosate and its formulations on another amphibian species, the California red-legged frog, and concluded that aquatic exposure to glyhphosate or its formulations posed no risk to this threatened species (EPA, 2008). Because EPA considered a wide range of application rates in their evaluation for the red-legged frog, this conclusion can also be applied to amphibians exposed to glyphosate from applications on GT alfalfa.

3.13.2 Threatened and endangered species

Alternative 1: No Action

Under this alternative RRA would remain regulated, and growers of conventional alfalfa would continue to use a multitude of herbicides for weed control. Many of the herbicides used in conventional alfalfa production have been found to have higher toxicity to certain animal species than glyphosate. Threatened and endangered species within and adjacent to fields of conventional alfalfa would continue to be exposed to these more toxic herbicides. The amphibian habitat in watersheds where conventional and organic alfalfa are grown would continue to be impacted by higher levels of tillage, soil erosion, sedimentation in runoff, and turbidity in ponds, lakes, and rivers than would otherwise be the case if RRA were grown.

Alternative 2: Partial Deregulation of RRA

Under partial deregulation, the acreage of RRA would likely increase with a concomitant increase of glyphosate use for weed control. Based on the information presented below, there is no expected impact based on the ecological safety assessment conducted for glyphosate discussed below (Mortensen et al., 2008) and growers implementation of glyphosate application practices required by Monsanto that are designed to protect threatened or endangered species.

Monsanto recently performed an updated assessment of the impact to threatened and endangered species of glyphosate application to GT crops. The results of this assessment were submitted to USDA as Monsanto Report No. RPN-2007-227 (Mortensen et al., 2008). Monsanto also prepared an endangered species assessment for terrestrial plants that was submitted to USDA (Honegger et al., 2008). The findings of these assessments are as follows:

- Threatened or endangered terrestrial or semi-aquatic plant species are not at risk from ground applications of glyphosate at rates less than 3.5 lb active ingredient per acre (ai/A). Since the maximum single application rate before or after crop emergence in GT alfalfa is 1.55 lb ai/A, no listed plant species are predicted to be at risk from ground application of glyphosate to RRA.
- • Threatened or endangered terrestrial or semi-aquatic plant species are not at risk from aerial applications of glyphosate at rates less than 0.70 lb ai/A. Since rates above 0.7 lb ai/A are needed to control a number of weed species, buffers for aerial application have been proposed by Monsanto (using an EPA-accepted drift model) to permit aerial application at rates up to 1.55 lb ai/acre while still predicting no impact on plant growth at the edge of the buffer. Monsanto has developed a web site, www.Pre-Serve.org, to

provide growers a means to determine if threatened or endangered plant species are potentially at risk from glyphosate applications that they are planning on GT crops. The requirement for growers to consult this web site has been incorporated into the Monsanto Technology/Stewardship Agreement and Technology Use Guide, an agreement that growers sign when purchasing any Monsanto GT seed. Through the implementation of the Pre-Serve web site and its mandated use by growers, threatened and endangered plant species are protected from potential effects from glyphosate use on RRA.

- Other taxa (including birds, mammals, insects, fish, amphibians, aquatic invertebrates, and aquatic plants) are not at risk from the use of glyphosate herbicides in alfalfa production. In addition, other taxa are not at risk from indirect effects resulting from habitat alteration from the use of glyphosate.

Amphibians use a wide range of aquatic habitats for their breeding sites and could be exposed to glyphosate in surface water. Considering the potential for aquatic exposure to glyphosate formulations from terrestrial uses, EPA recently evaluated the effect of glyphosate and its formulations on the California red-legged frog (CRLF). EPA concluded that aquatic exposure to glyphosate and its formulations posed no risk to this threatened species (EPA, 2008). As a part of the endangered species effects assessment for the California red-legged frog, EPA evaluated the effect of glyphosate at application rates up to 7.95 lb ai/A. Based on this assessment, the application of glyphosate at the maximum, single, in-crop application rate specified on the EPA-approved label for RRA (1.55 lb ai/A) would have no effects on threatened and endangered species of fish, amphibians, birds, or mammals.

Although not specifically discussed in the assessment, it can also be determined that there would be no effects of glyphosate or its formulations on threatened or endangered vascular aquatic plants and aquatic invertebrates (EPA, 2008). For terrestrial invertebrates, it was determined that there were no effects on non-endangered species. Although not specifically stated in the CRLF assessment, exposure levels from spray drift to threatened or endangered invertebrates adjacent to RR alfalfa fields are below the level[44] that would result in a conclusion of risk. Additional information has been provided to EPA to also support a conclusion of no risk for small terrestrial invertebrates that might be present in the field at the time of glyphosate application. For terrestrial plants, the potential for effects on non-endangered species was assessed, and using the endpoints and EECs provided, it could be determined that there would

[44] Screening level drift assumptions are one percent for ground applications and five percent for aerial applications.

be no effects on terrestrial plants from ground applications at the maximum single in-crop application rate for RRA.

3.13.3 Potential impact of exposure to RRA

APHIS analyzed the potential impacts to threatened and endangered species from directly contacting, consuming, or hybridizing with RRA and/or their progeny. This analysis considered the effect of production of RRA on designated critical habitat or habitat proposed for designation. The results are as follows:

- RRA is not expected to become more invasive in natural environments or have any difference in effect on critical habitat than their parental non-GT line in the absence of glyphosate selection.
- Analysis of forage samples from several locations demonstrates that RRA is compositionally and nutritionally equivalent to other alfalfa varieties currently on the market. It is not expected to have adverse nutritional effects on any threatened and endangered species that feeds upon it. The RRA CP4 EPSPS protein does not have toxic or pathogenic effects that would affect threatened and endangered species or their critical habitat.
- RRA is not expected to form hybrids with any state or federally listed threatened or endangered species of plant or any plant species proposed for federal listing.

Based on this assessment, APHIS could not identify any difference between the impacts from exposure to RRA and the impacts from exposure to other alfalfa varieties (conventional and organic varieties). Consequently, there would be little or no differences between Alternatives 1 and 2 in terms of the exposure of threatened and endangered species to RRA.

3.14 HUMAN HEALTH AND SAFETY

3.14.1 Consumer health and safety

Because RRA is compositionally and nutritionally identical to non-RRA and because alfalfa forage and seed are not directly consumed by humans, the main issue regarding consumer health and safety is potential dietary exposure to glyphosate herbicide residues. The general public may be exposed to herbicides used on RRA if they consume animal commodities arising from livestock fed on the treated alfalfa. For the reasons described below, this risk is very small, and there would be little or no differences between Alternatives 1 and 2 in terms of the impact of regulation or partial deregulation of RRA on consumer health and safety.

Consumption of adjacent crops impacted by spray drift is a theoretically possible route of exposure, but is not a normal part of dietary risk assessment (EPA, 2000). The predominant route of potential dietary glyphosate exposure to consumers linked to RRA is via consumption of meat / milk from livestock fed on the treated alfalfa. EPA's procedures to estimate dietary exposure fully account for these processes (EPA, 2000; EPA, 1993). EPA has determined that there is a reasonable certainty that no harm will result from aggregate exposure to glyphosate residues (71 Fed. Reg. 76180 (Dec. 20, 2006)). According to the RED (EPA, 1993), glyphosate has relatively low oral and dermal acute toxicity and has been placed in Toxicity Category III for these effects (Toxicity Category I indicates the highest degree of acute toxicity, and Category IV the lowest). The acute inhalation toxicity study was waived because glyphosate is nonvolatile and because adequate inhalation studies with end-use products exist and show low toxicity.

Glyphosate is already used for weed control with conventional alfalfa and other GT crops, including GT corn, GT soybeans, and GT cotton. In addition, it is registered for use in weed control with several fruits and vegetables, and tolerances are established in the consumable commodities of these crops. The current upper estimates of exposure risk for glyphosate are based on highly conservative fruit and vegetable intake rates with an assumed high estimated amount of glyphosate residue. The current aggregate dietary risk assessment completed by EPA concludes there is no concern for any subpopulation regarding exposure to glyphosate, including the use on many fruits and vegetables (71 Fed. Reg. 76180 (Dec. 20, 2006)). Moreover, the potential exists for decreases in the applications and subsequent residues of more toxic herbicides if RRA is partially deregulated.

The use of glyphosate does not result in adverse effects on development at non-maternally toxic doses, reproduction, or endocrine systems in humans and other mammals (EPA, 1993; WHO, 2004; ECETOC, 2009). Under present and expected conditions of use, glyphosate does not pose a health risk to humans (EPA, 1993). Additionally, the nature of glyphosate residue in plants and animals is adequately understood, and studies with a variety of plants indicate that uptake of glyphosate from soil is limited. The material that is taken up is readily translocated throughout the plant. In animals, most ingested or absorbed glyphosate is eliminated in urine and feces. As discussed in Section 3.10, no impacts from consumption of food or feed containing the CP4 EPSPS protein would be expected.

3.14.2 Hazard identification and exposure assessment for field workers

The main issue regarding the health and safety of field workers and RRA is potential worker exposure to glyphosate used for weed control. For the reasons described below, the health risk

from field worker exposure to glyphosate is small when used in accordance with labeling. There would be little or no differences between Alternatives 1 and 2 in terms of the impact of regulation or partial deregulation of RRA on field worker health and safety.

Glyphosate is already used for weed control with conventional alfalfa and other GT crops, including GT corn, GT soybeans, and GT cotton. In addition, it is registered for use in weed control with several fruits and vegetables. So the potential for field worker exposure to glyphosate will continue to exist whether RRA is regulated or deregulated.

With regard to subchronic and chronic toxicity, one of the more consistent effects of exposure to glyphosate at high doses is reduced body weight gain compared to controls. Body weight loss is not seen in multiple subchronic studies, but has at times been noted in some chronic studies at excessively high doses ≥ 20,000 ppm in diet (WHO, 2004). Other general and non-specific signs of toxicity from subchronic and chronic exposure to glyphosate include changes in liver weight, blood chemistry (may suggest mild liver toxicity), and liver pathology (USDA FS, 2003). Glyphosate is not considered a carcinogen; it has been classified by EPA as a "Group E carcinogen", which means that it shows evidence of non-carcinogenicity for humans (EPA, 1993).

EPA's human health analysis considers both the applicator and bystander as having the potential for exposure to glyphosate. Based on the toxicity of glyphosate and its registered uses, including use on GT crops, EPA has concluded that occupational exposures (short-term dermal and inhalation) to glyphosate are not of concern because no short-term dermal or inhalation toxicity endpoints have been identified for glyphosate (71 Fed. Reg. 76180 (Dec. 20, 2006)).

Additional evidence to support the EPA conclusion can be found in the *Farm Family Exposure Study*, a biomonitoring study of pesticide applicators conducted by independent investigators (Acquavella et al., 2004). This biomonitoring study determined that the highest estimated bodily adsorption of glyphosate as the result of routine labeled applications of registered glyphosate-based agricultural herbicides to crops, including GT crops, was approximately 400 times lower than the reference dose (RfD) established for glyphosate. Furthermore, investigators determined that 40 percent of field workers (applicators) did not have detectable exposure on the day of application, and 54 percent of the field workers had an estimated bodily adsorption of glyphosate more than 1000 times lower than the RfD (Acquavella et al., 2004). Use patterns and rates for RRA are typical of most glyphosate agronomic practices. Therefore, the partial deregulation of RRA would not significantly increase the exposure risk to pesticide applicators.

Finally, the biomonitoring study also found little evidence of detectable exposure to individuals on the farm who were not actively involved with or located in the immediate vicinity of application of glyphosate-based herbicides to crops. Considering the similarity of the use pattern and application rates of the glyphosate products in this study compared to those registered for use on RRA and GT crops in general, bystander exposure attributed to the use of glyphosate on GT crops is expected to be negligible.

Based on the above information, the use of currently registered herbicide products containing glyphosate in accordance with the EPA labeling requirements will not pose unreasonable risks or adverse effects to field workers or bystanders. In general, the herbicidal activity of glyphosate is due primarily to a metabolic pathway that does not occur in humans or other animals, and, thus, this mechanism of action is not directly relevant to the human health risk assessment. EPA considers glyphosate to be of low acute and chronic toxicity by the dermal route of exposure. Glyphosate is considered a Category IV dermal toxicant and is expected to cause only slight skin irritation (USDA APHIS, 2009).

3.15 SOCIAL AND ECONOMIC IMPACTS OF THE PROPOSED PARTIAL DEREGULATION

APHIS has studied the potential socioeconomic impacts of fully deregulating RRA (USDA APHIS, 2009, pp. 125-145 & Appendix S). Although the types of potential socioeconomic impacts discussed in the draft EIS under full deregulation would remain the same as under this proposed partial deregulation, the scale (extent and scope) of each impact would be significantly more limited. The proposal restricts (excludes) forage planting of RRA within county-level proximity to 99.5 percent of the U.S. alfalfa seed crop production areas and it would place highly stringent isolation conditions and other requirements on a small, pre-defined group of RRA seed producers.

Simply stated, protection of conventional and organic seed purity has been identified as an important component for the coexistence of GE, conventional and organic agricultural crops, including alfalfa. As it is primarily a geographically-structured approach parsed to the county level by seed vs. forage crop production criteria, the partial deregulation is intended to preclude the possibility for socio-economic impacts (favorable or unfavorable) specifically inter-related with gene flow into >99.5 percent of the U.S. alfalfa seed crop. The remaining approximately 0.5 percent of the seed crop is also unlikely to be impacted because when and if grown in local proximity to a RRA forage crop (<165 ft), the RRA forage producers would be required to

mitigate the amount of available RRA pollen by cutting the RRA hay crop prior to 10 percent bloom.

USDA has clearly endorsed coexistence of GE, conventional and organic growers, crops and markets. During the period in which USDA/APHIS finalizes a court-ordered EIS and prepares a record of decision on the deregulation of RRA, the terms of the proposed Partial Deregulation cautiously parse out the areas of primary "gene flow interface" between RRA and conventional alfalfa, enabling immediate RRA grower benefits without interfering with conventional and organic crops and markets. The proposed partial deregulation conditions will enable, without restriction, the continued supply of conventional variety seeds and basic generation seeds for export, organic or domestic use. It would also allow producers to choose to use or not use RRA on approximately seventy-eight percent (78%) of U.S. forage production acres and enable a nominal number of RRA seed growers on seed production acres where extraordinary isolation exists. The actual adoption of the technology by forage growers is anticipated to be some fraction of the eligible (allowed) alfalfa acreage total in each region of the U.S. (Appendix G). Those most likely to adopt the technology are those producers serving dairy herd forage needs. However, pending completion of an EIS and a final deregulation decision, this partial deregulation would not uniformly enable all forage or seed growers the choice to participate in the socio-economic benefits of the technology, and moreover, in future years, it is possible that RRA seed supplies could fall short of RRA seed demand or that forage market inequities might develop between competing geographies with and without the technology.

It is likely that through improvements to weed management, the widespread adoption of the RRA technology by growers could result in economic benefits related to the quantity and improved forage quality of U.S. hay supplies (see below). Forage producers and dairy producers may most directly benefit from more abundant supplies of dairy quality forage with fewer weeds. Organic forage, dairy, and other food producers would also be likely to economically benefit from increased market share related to the newly-heightened market differentiation between organic and non-organic dairy and forage production strategies, e.g., the organic dairy food customer base may increase if a proportion of conventional consumers begin to purchase organic foods due to a negative perception of GE alfalfa. Since the RRA crops were first grown (2005-2007) the organic dairy sector has experienced market growth. According to several independent analyses (Putnam and Undersander, 2009, attached as Appendix I; Van Deynze et al., 2008; NAFA, 2008d; Putnam, 2006; Putnam, 2007), organic forage supplies and organic farming practices are unlikely to be at economic risk, adversely

impacted, or materially affected by the deregulation or growing of RRA. Simple, minimal/no-cost effective methods are available to organic and conventional forage producers wishing to avoid RRA irrespective of their neighbor's choice to grow RRA seed or hay crops. Specifically, organic or non-GE forage producers need only to cut their hay before seed ripens, purchase non-GE planting seeds qualified for organic use and maintain organic hay lot segregation; i.e., follow current routine farm plans required by the NOP. Organic dairy or livestock producers will continue to grow and/or purchase only organically qualified (identity-preserved, segregated) feedstuffs; i.e., follow current routine farm plans required by the NOP. A minority, approximately 3 to 5 percent, of total alfalfa production may be sensitive to GE traits (Putnam, 2007). Therefore, it may be reasoned that a similar percentage of U.S. alfalfa forage growers would opt to take these nominal steps to avoid RRA trait presence in their conventional hay crops.

Forage production. Benefits to farm socio-economics include improvements to grower profitability, consistent and abundant on-farm forage supply, and, the ease and flexibility of weed control.

As indicated above, in the defined geographies where RRA forage production would be allowed with restrictions for new plantings (Table 1-1 and Appendix B of this ER), forage producers would have a new tool available for weed management throughout the life of the stand. Forage producers (n=201) who have previously commercially used the RRA technology report an average increase in productivity of 0.9 total acres per year (T/A/yr) which translates to approximately $100 acre per year (A/year) incremental crop value at an average hay price of $110 total (T) (RRA Satisfaction Study, Market Probe, 2008, attached as Appendix H). Over the life of the stand (e.g., 3 to 5 years), the approximate incremental value of RRA forage production is $300 to $500 per acre (A).

Like growers of other GE crops, many growers of RRA also report experiencing intangible social benefits (see examples of Public Comments to draft EIS included in Appendix F). Specifically, growers report that the RRA technology improves their farming experience in that weed control is easier, simpler, more reliable (less risk of failure), herbicide timing is more flexible and crop injury (stress) is lessened. They also acknowledge the lessened risk to water sheds and to herbicide applicators (self, family and employees) compared to several other herbicide choices. Relative to their economic benefits and risks, currently available weed management strategies may not be implemented at all because they can be expensive, ineffective on target weeds, restricted in use due to environmental or worker safety issues, difficult to apply at the correct time for good control, and some measures reduce alfalfa crop yield or stand longevity more than

the weeds (e.g., early clipping, companion and cover crops). RRA growers note that the RRA technology is especially beneficial for weed control during the early seedling establishment period when the new planting can be at risk of failure (complete loss) due to unchecked weed competition. Although there are many reasons why alfalfa plantings fail in the first year, growers who adopt RRA would likely have less exposure to economic risk and intangible uncertainty associated with the possibility of losing their valuable planting inputs, meanwhile ensuring a more consistent supply of nutritious forage for livestock than the alfalfa growers not adopting the technology.

Seed Production. Socio-economic benefits related to RRA seed production include: improved profitability for RRA seed growers; the benefits described above associated with improved weed control; and a seed supply of new RRA varieties targeting new production niches, thus enabling the forage benefits described herein.

The seed producer consortia outlined in Table 1-2 have several things in common. These growers all produced RRA seed in 2006, 2007, 2008 and/or 2009. They will receive FGI training on RRA Seed Production Best Practices and will be monitored by FGI for compliance as required by the NAFA BMP and the proposed conditions for partial deregulation. These growers also all produce seed in a setting that allows substantial isolation from conventional alfalfa seed production. Table 1-2 shows the existing isolation, and the minimum required isolation required in future years under the terms of this partial deregulation. In all cases the required isolation exceeds the NAFA RRA Seed Production Best Practices.

Pollen-mediated gene flow is inversely proportional to isolation distance, and varies by introduced pollinator species. Any new RRA seed production with the growers and production areas outlined in Table 1-2 will have a minimal impact on conventional or organic seed production targeted for either U.S. or export markets.

SECTION 4.0 CUMULATIVE IMPACTS

This section discusses the cumulative impacts that may be associated with Alternative 2, when combined with other recent past, present, and reasonably foreseeable future actions within the affected environment. Cumulative impacts that will occur are expected to be negligible.

Cumulative impacts occur when the effects of an action are added to the effects of other actions occurring in a specific geographic area and timeframe. The cumulative impact analysis follows CEQ's guidance: Considering Cumulative Effects Under the National Environmental Policy Act (CEQ, 1997). The steps associated with the analysis include:

- Specify the class of actions for which effects are to be analyzed.
- Designate the appropriate time and space domain in which the relevant actions occur.
- Identify and characterize the set of receptors to be assessed.
- Determine the magnitude of effects on the receptors and whether those effects are accumulating.

4.1 CLASS OF ACTIONS TO BE ANALYZED

This analysis addresses regional and national actions that may have impacts that may accumulate with those of the proposed partial deregulation measures.

4.2 GEOGRAPHIC AND TEMPORAL BOUNDARIES FOR THE ANALYSIS

As described in Section 2, over the past 60 years, the number of alfalfa hay acres harvested annually in the U.S. has ranged between 20.7 million acres (2010) and 29.8 million acres (1957), with peak tonnage of hay production in the mid-1980s (USDA ERS, 2010a). In 2006, 20.9 million acres of alfalfa was harvested for forage. (In contrast, 122.1 acres of alfalfa was harvested for seed.) Alfalfa is grown for forage throughout the U.S. Based on 2008 production data by county, the four major U.S. alfalfa producing regions include the north-central, west, northeast, and south, with the north-central and the west regions being the highest producing regions in the U.S.

Under this proposal, we anticipate that any future alfalfa planting under partial deregulation will conform to the geographic use restrictions described herein, with the exception of a minimal number of acres (e.g. less than 100 acres) that may be produced under APHIS permit. In the event this proposal is granted, the small and declining number of RRA acres planted under APHIS permit will not have incremental cumulative impact on any of the resource areas.

Activities relevant to the cumulative impacts analysis have been identified from reviews of information available from government agencies, such as NEPA documents, land-use and natural resource management plans, and from private organizations. Not all actions identified in this analysis would have cumulative impacts on all resource areas.

4.3 RESOURCES ANALYZED

Issues evaluated in this cumulative impacts analysis include some of the resource areas discussed in Sections 2 and 3 including land use, air quality and climate, water quality, biological, and human health and safety. In addition, specific topics analyzed include: cumulative impacts related to any possibility of development of glyphosate resistant weeds, and cumulative impacts of potential increased glyphosate usage with the cultivation of GT crops.

4.4 CUMULATIVE IMPACTS RELATED TO THE DEVELOPMENT OF GLYPHOSATE RESISTANT WEEDS

Glyphosate offers many benefits to the grower as a weed control product. Glyphosate controls a broad spectrum of grass and broadleaf weed species present in U.S. production fields, has flexible use timings, and when used in GT crops, has a very high level of crop safety. As the adoption of GT crops has grown, the use of glyphosate has increased over the past several years. As discussed in Section 3, with the increased use of glyphosate, there is also the potential for increased selection pressure for the development of new glyphosate-resistant weed populations and/or new glyphosate-resistant weed species.

As discussed in Section 2.4, there is a low probability for the development of new glyphosate-resistant weed populations and/or development of new resistance weed species from the use of glyphosate herbicides in conjunction with plantings of RR alfalfa. The expected use pattern of herbicides, including glyphosate, in alfalfa and the alfalfa production practices (e.g. frequent mowing) provides a basis for retarding the development of new resistance. It also provides a basis for managing resistance that may be present from movement of a resistant weed seed into an alfalfa field or cross-pollination from a resistant weed to a sexually compatible weed within an alfalfa field.

As discussed in Section 3.11.14, market research studies indicate that growers of glyphosate-tolerant crops are increasingly taking measures to minimize the potential for development of glyphosate resistance. Based on the adoption of these measures by growers of other GT crops such as GT corn, GT soybeans, and GT cotton (Frisvold et al., 2009), similar adoption of these measures by GT alfalfa growers is anticipated. In all three of these other GT crops, growers are

adopting best management practices, in particular the more frequent use of complementary herbicides in a glyphosate-based weed management programs in corn (Givens et al., 2009; Frisvold et al., 2009). The key best management practices recommended by industry and academics to control against weed resistance are as follows : a) identifying weeds and monitoring for escapes to determine if current practices need to be modified to achieve acceptable levels of weed control, b) using proper herbicide rates and timing, c) using crop rotation to facilitate use of different modes of action over time, d) using agronomic management practices to supplement herbicide weed control, e) alternating herbicides with different modes of action, and e) tank mixing herbicides of different modes of action (HRAC, 2009; Orloff et al., 2009; Monsanto, 2010a).

Increased glyphosate use is not expected in the major GT crops (corn, soybeans and cotton), as GT usage in these crops is high and likely not to increase beyond current levels. As discussed above and in Section 3.11, there is a high level of awareness among growers of these crops of the need to minimize the potential for development of glyphosate resistance, and evidence that growers are implementing management practices to prevent the development of glyphosate resistant weeds.

These management practices for all glyphosate-tolerant crops, combined with the specific alfalfa weed management practices discussed in Section 2.4, will together help minimize the cumulative potential for development of glyphosate resistant weeds under Alternative 2. Thus, Alternative 2 is not expected to contribute to cumulative adverse impacts on the development of glyphosate-resistant weeds.

4.5 CUMULATIVE IMPACTS OF POTENTIAL INCREASED GLYPHOSATE USAGE

The increase in glyphosate used under the proposed interim measures described in this ER (Alternative 2), would be minimal. Assuming a 50 percent market share, the amount of glyphosate applied to RRA would be 1,627,500 lb a.e (0.5 x 21 million total alfalfa acres X 1.55 lb a.e./A). Calculating from Table N-3 on page N-16 in the draft EIS, total use of glyphosate on corn, cotton, soybean, and wheat is equal to 126,308,000 lbs. Therefore, even if glyphosate is used on 50 percent of total alfalfa acres, the glyphosate use on alfalfa would be 1.3 percent of the glyphosate used on these four major crops.

According to the USDA ERS (2009), U.S. farmers have adopted genetically engineered crops widely since their introduction in 1996. Soybeans and cotton genetically engineered with herbicide-tolerant traits have been the most widely and rapidly adopted GE crops in the U.S.,

followed by insect-resistant cotton and corn. Figure 4-1 shows the percentage of acres of genetically engineered crops in the U.S. between 1996 and 2009. Appendix G charts data from Monsanto/FGI of the anticipated adoption of RRA under Alternative 2 over a 10 year period.

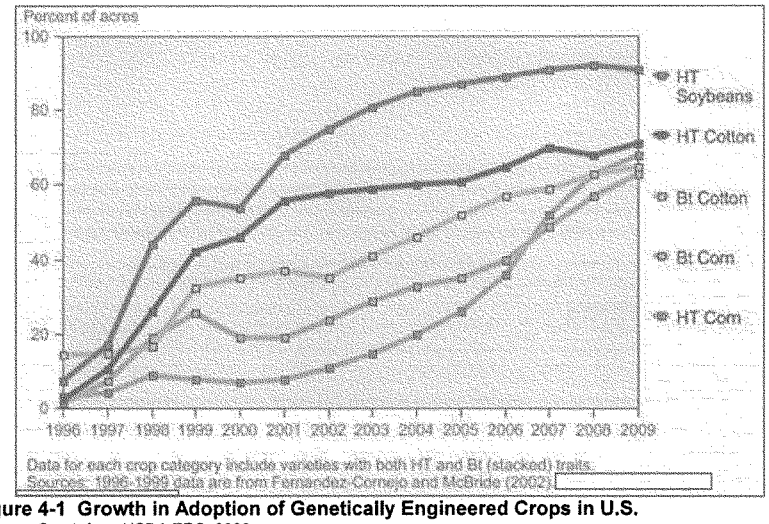


Figure 4-1 Growth in Adoption of Genetically Engineered Crops in U.S.
Source: Graph from USDA ERS, 2009

Herbicide-tolerant crops, which are engineered to survive application of specific herbicides that previously would have damaged the crop, provide farmers with a broader variety of options for effective weed control. Based on USDA survey data, herbicide tolerant soybeans went from 17 percent of U.S. soybean acreage in 1997, to 68 percent in 2001 and 91 percent in 2009. Plantings of herbicide tolerant cotton expanded from approximately 10 percent of U.S. acreage in 1997 to 56 percent in 2001 and 71 percent in 2009. The adoption of herbicide tolerant corn was slower in previous years, but has reached 68 percent of U.S. corn acreage in 2009 (USDA ERS, 2009).

Corn growers use the largest volume of herbicides. Approximately 96 percent of the 62.2 million acres used for growing corn in the 10 major corn-producing States were treated with more than 164 million pounds of herbicides in 1997 (USDA ERS, 2009). Soybean production in the U.S. also uses a large amount of herbicides. Approximately 97 percent of the 66.2 million soybean acres in the 19 major soybean-producing States were treated with more than 78 million pounds of herbicides in 1997 (USDA ERS, 2009). Cotton production relies heavily on

herbicides to control weeds, often requiring applications of two or more herbicides at planting and postemergence herbicides later in the season (Culpepper and York, 1998). Close to 28 million pounds of herbicides were applied to 97 percent of the 13 million acres devoted to upland cotton production in the 12 major cotton-producing States in 1997 (USDA ERS, 2009).

Pesticide use on corn and soybeans has declined since the introduction of GE corn and soybeans in 1996. Several studies have analyzed the agronomic, environmental, and economic effects of adopting GE crops, including actual pesticide use changes associated with growing GE crops (McBride and Brooks, 2000; Fernandez-Cornejo, Klotz-Ingram, and Jans, 1999, 2002; Giannessi and Carpenter, 1999; Culpepper and York, 1998; Marra et al., 1998; Falck-Zepeda and Traxler, 1998; Fernandez-Cornejo and Klotz-Ingram, 1998; Gibson et al., 1997; ReJesus et al., 1997; Stark, 1997). Many of these studies have concluded that herbicide use is reduced with herbicide-tolerant varieties (USDA ERS, 2009).

Studies conducted by the USDA shows an overall reduction in pesticide use related to the increased adoption of GE crops. Based on the adoption of GE crops between 1997 and 1998 (except for herbicide-tolerant corn, which is modeled for 1996-97), the decline in pesticide use was estimated to be 19.1 million acre-treatments, 6.2 percent of total treatments (USDA ERS, 2009). Most of the decline in pesticide acre treatments was from less herbicide used on soybeans, which accounts for more than 80 percent of the reduction (16 million acre-treatments) (USDA ERS, 2009).

The adoption of herbicide-tolerant crops such as RRA, GT soybeans, and GT corn results in the substitution of glyphosate for previously used herbicides. The GT crops allow farmers to limit and simplify herbicide treatments based around use of glyphosate, while a conventional weed control program can involve multiple applications of several herbicides. In addition, and more importantly, herbicide-tolerant crops often allow farmers to use more benign herbicides (USDA ERS, 2009).

There are known benefits associated with the use of glyphosate herbicides compared to herbicides currently used by alfalfa producers. Glyphosate has documented favorable characteristics with regard to risk to human health, non-target species, and the environment (Malik et al., 1989; Williams et al., 2000). Glyphosate is classified by the EPA as Group E (evidence of non-carcinogenicity for humans) (57 Fed. Reg. 8739 (Mar. 12, 1992)). In 1998, the EPA granted Reduced Risk status for an expedited review of the submitted residue data package supporting the use of glyphosate.

Petitions for non-regulated status are pending for additional events or lines of GT soybean, corn, sugar beets, and creeping bentgrass (USDA APHIS, 2010). If deregulated, the production of new GT crops would lead to increased glyphosate application, and in the instances that it is cultivated in or near the same geographic areas where RRA is produced, this could lead to a cumulative impact on non-target plants impacted by glyphosate. However, given that these acres are already being used for agricultural production (in the case of corn and soybeans, most likely through a RR cropping system), these plants are likely already exposed to glyphosate or other pesticides.

Studies of the relationship between genetically engineered crops and herbicide use has shown that an increase in GT crops can result in a decrease in mechanical tillage (Brimner et al., 2005; Fernandez-Cornejo, 2006; Gianessi and Reigner, 2006; Kleter et al., 2007; Sankula, 2006; Johnson et al., 2008). The potential cumulative impact from this reduction in mechanical tillage is discussed in the following sections.

4.6 CUMULATIVE IMPACTS ON LAND USE, AIR QUALITY AND CLIMATE

As discussed in Section 2, alfalfa acreage has fluctuated little for the past 60 years, although acreage has generally been declining since the mid-1980s. Acreage used for alfalfa would not be expected to be impacted by increased RRA plantings. Therefore, as discussed in Section 3, Alternative 2 is not expected to impact land use directly or indirectly, other than the anticipated shift of certain acreage from conventional or organic alfalfa production to RRA production as a result of a partial deregulation (See Appendix G charting anticipated adoption of RRA under Alternative 2), and no cumulative impacts on land use are anticipated from Alternative 2.

As discussed in Section 3, Alternative 2 is expected to have positive impacts on air quality and climate, primarily resulting from reduced tillage. Consequently, Alternative 2 is not expected to have any adverse cumulative impacts on air quality or climate.

4.7 CUMULATIVE IMPACTS ON WATER QUALITY

As discussed in Section 3, the advent of GT crops and the use of post-emergent herbicides that could be applied over a crop during the growing season have facilitated the use of conservation tillage farming practices, since weeds could be controlled after crop growth without tilling the soil (USDA ERS, 2009). The use of GT crops (particularly soybeans) has intensified that trend since it often allows a more effective and less costly weed control regime than using other post-emergent herbicides (USDA ERS, 2009; Carpenter and Gianessi, 1999).

The impact of conservation tillage (including no-till, ridge-till, and mulch-till) in controlling soil erosion and soil degradation is well documented (Edwards, 1995; Sandretto, 1997). By leaving substantial amounts of plant matter over the soil surface, conservation tillage 1) reduces soil erosion by wind; 2) reduces soil erosion by water; 3) increases water infiltration and moisture retention; 4) reduces surface sediment and water runoff; and 5) reduces chemical runoff (USDA ERS, 2009).

Glyphosate may potentially be found in surface water runoff when erosion conditions lead to the loss of surface particles. However, as discussed in Section 3, partial deregulation of GT crops typically leads to an increase in conservation tillage and no tillage systems, which results in less mechanical disturbance of the soil during alfalfa cultivation and thereby decrease the loss of surface soil. Consequently, given that glyphosate binds strongly to soil particles and has no herbicidal activity after binding to soil, no-tillage and conservation tillage are expected to further reduce the likelihood of any impact of surface water runoff (Wiebe and Gollehon, 2006). Therefore, no cumulative adverse impacts to surface water or groundwater are anticipated.

4.8 CUMULATIVE BIOLOGICAL IMPACTS

For non-target terrestrial species, available ecological assessments in EPA RED (EPA, 2003) documents or registration review summary documents provide the support that the use of glyphosate represents reductions in chronic risk to birds compared to benfluralin, norflurazon, paraquat, sethoxydim, and trifluralin, and in acute risk to small mammals in comparison to bromoxynil, EPTC, and paraquat. For other alfalfa herbicide products, as well as glyphosate, no significant risks to birds or other non-target terrestrial species were indicated in the available information.

For non-target aquatic species, Tables 4-1, 4-2, and 4-3 provide summaries of the estimated exposure and hazard information for the traditional herbicides used in conventional alfalfa production, and present quantitative comparisons of the derived Risk Quotients. Exposure, defined as the EEC, was calculated for all products using the assumptions (assuming aerial application) of 5 percent drift of spray applied to a one-acre field onto water and 5 percent runoff from 10 treated acres into a one-acre pond six feet in depth. Herbicide treatments were based on the maximum single application rate for alfalfa taken from product labels. Hazard information (LC50 or EC50) for each active ingredient was taken from the EPA Ecotoxicology One-Liner Database (if available) or other EPA source documents and summarized in Tables 4-1, 4-2, and 4-3 as the upper and lower values from the range of values reported. Hazard information for the end-use formulated products is generally not readily available; thus, this analysis is a

comparison based solely on the active ingredients. Any label warnings and other available hazard and/or risk descriptions for non-target aquatic species are also included. The Risk Quotient is determined for each active ingredient by dividing the EEC by the hazard (LC50 or EC50) value.

Plants potentially at risk from the use of glyphosate are potentially at risk from the use of any herbicide. Like most herbicides, plants are highly sensitive to glyphosate. Monsanto has developed a program named Pre-Serve to address the use of glyphosate, including aerial spraying, in areas where threatened plants may be located. Following use instructions on the EPA-approved label and use limitations described in Pre-Serve would address any such risk of exposure. Federal law requires pesticides to be used in accordance with the label. Conservation tillage and no tillage practices provide additional assurance that the impact to aquatic plants is reduced by decreasing soil-laden runoff.

The EPA-approved labels for products containing 2,4-DB, celthodim, sethoxydim, and trifluralin include warnings of toxicity or adverse effects to fish, and/or aquatic invertebrates and/or aquatic plants. Risk Quotients that exceed the Trigger Value of 0.5 for aquatic animals and 1.0 for aquatic plants are highlighted in bold text in Tables 4-1, 4-2, and 4-3 as exceeding a Level of Concern, based on EPA Ecological Effects Rejection Analysis and Deterministic Risk Characterization Approach. Current alfalfa herbicide products containing benfluralin, bromoxynil, diuron, hexazinone, metribuzin, norflurazon, paraquat, terbacil, and trifluralin are shown to exceed these Levels of Concern. As supported by the EPA designation of reduced risk for application of glyphosate to alfalfa, glyphosate is a more environmentally preferred herbicide compared to other herbicides currently used in alfalfa production since glyphosate is generally less toxic and has favorable degradation properties.

Table 4-1. Comparison of Potential Effects of Glyphosate and Alfalfa Herbicides on Freshwater Fish

Active Ingredient	Max. lb/acre (single appl.)	EEC[1] (ppm)	Fish LC_{50} (a.i.)[2] Range (ppm)		Fish Risk Quotient[3] Range		Classification / Label Warnings
			low	high	worst	best	
Glyphosate	1.55	0.052	45	140	0.001	0.0004	
2,4-DB	1.7	0.057	2	16.8	0.029	0.003	Toxic to fish
Benfluralin 4	1.5	0.051	NA	0.0317		**1.6**	
Bromoxynil 4	0.375	0.013	0.023	0.17	**0.55**	0.07	
Clethodim	0.25	0.008	19	33	0.0004	0.0003	
Diuron	2.4	0.081	0.71	14.2	0.11	0.006	
EPTC	3.9	0.131	11.5	27	0.011	0.005	
Hexazinone	1.5	0.051	> 100	274	< 0.0005	0.0002	
Imazamox	0.047	0.002	> 94	> 122	< 0.00002	< 0.00001	
Imazethapyr	0.094	0.003	> 112	423	< 0.00003	0.000007	
Metribuzin	1	0.034	42	> 100	0.0008	< 0.0003	
Norflurazon	0.98	0.033	8.1	16.3	0.004	0.002	
Paraquat	0.8	0.027	> 1	156	< 0.027	0.0002	
Pronamide	2	0.067	72	350	0.0009	0.0002	
Sethoxydim	0.47	0.016	170	265	0.0001	0.0001	Toxic to aquatic organisms.
Terbacil	1.2	0.040	46.2	112	0.0009	0.0004	
Trifluralin[4]	2	0.067	0.0084	0.210	**8.0**	0.32	Extremely toxic to freshwater, marine and estuarine fish.

NA = information not available

1 EEC refers to the Estimated Environmental Concentration, which assumes that a one-acre pond, six feet deep receives 5% drift from a one-acre field and 5% runoff from a 10-acre field.

2 Aquatic LC50 values obtained from the 2010 EPA Ecotoxicology One-Liner Database, except where Footnote 4 is indicated.

3 Risk Quotient is EEC/LC50. Risk Quotient **Bolded** if > 0.5 = Level of Concern [criteria from EPA Ecological Effects, Rejection Analysis]. Risk Quotients >0.1 result in classification for Restricted Use (http://www.epa.gov/oppefed1/ecorisk_ders/toera_risk.htm#Deterministic).

4 Toxicity values are from the available Reregistration Eligibility Documents, United States Environmental Protection Agency.

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Table 4-2. Comparison of Potential Effects of Glyphosate and Alfalfa Herbicides on Freshwater Aquatic Invertebrates

Active Ingredient	Max. lb/acre (single appl.)	EEC[1] (ppm)	Invertebrate EC_{50} (a.i.)[2] Range (ppm)		Invertebrate Risk Quotient[3] Range		Classification / Label Warnings
			low	high	worst	best	
Glyphosate	1.55	0.052	134	780	0.0004	0.00007	
2,4-DB	1.7	0.057	NA	25		0.002	
Benfluralin 4	1.5	0.051	NA	0.0218		**2.3**	
Bromoxynil 4	0.375	0.013	0.011	0.096	**1.1**	0.1	
Clethodim 5	0.25	0.008	NA	20.2		0.0004	
Diuron	2.4	0.081	0.16	1.1	**0.51**	0.07	
EPTC	3.9	0.131	3.5	66	0.040	0.002	
Hexazinone	1.5	0.051	178	> 1000	0.0003	< 0.00005	
Imazamox	0.047	0.002	> 94.3	> 122	< 0.00002	< 0.00001	
Imazethapyr	0.094	0.003	> 109	> 1000	< 0.00003	< 0.000003	
Metribuzin	1	0.034	4.2	> 65	0.008	0.0005	
Norflurazon	0.98	0.033	5.3	15	0.006	0.002	
Paraquat	0.8	0.027	NA	1.2		0.020	
Pronamide	2	0.067	> 4	> 6	< 0.02	< 0.01	
Sethoxydim	0.47	0.016	NA	78		0.0002	Toxic to aquatic organisms.
Terbacil	1.2	0.040	65	> 1000	0.0006	< 0.00004	
Trifluralin [4]	2	0.067	0.56	2.2	0.12	0.03	Extremely toxic to aquatic invertebrates.

NA = information not available or not applicable

1 EEC refers to the Estimated Environmental Concentration, which assumes that a one-acre pond, six feet deep receives 5% drift from a one-acre field and 5% runoff from a 10-acre field.

2 Aquatic Invertebrate EC50 values obtained from the 2010 EPA Ecotoxicology One-Liner Database, except where Footnote 4 is indicated.

3 Risk Quotient is EEC/EC50. Risk Quotient **Bolded** if > 0.5 = Level of Concern [criteria from EPA Ecological Effects, Rejection Analysis]

4 Toxicity values are from the available Reregistration Eligibility Documents, United States Environmental Protection Agency.

5 EC50 value is from a study using a 25.6% ai concentration.

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Table 4-3. Comparison of Potential Effects of Glyphosate and Alfalfa Herbicides on Aquatic Plants (Algae and Duckweed)

Active Ingredient	Max. lb/acre (single appl.)	EEC[1] (ppm)	Aquatic Plant EC_{50} (a.i.)[2] Range (ppm)		Aquatic Plant Risk Quotient[3] Range		Classification / Label Warnings
			low	high	worst	best	
Glyphosate	1.55	0.052	0.8	38.6	0.065	0.001	
2,4-DB	1.7	0.057	NA	> 0.932		< 0.061	
Benfluralin [4]	1.5	0.051	NA	0.1		0.51	
Bromoxynil [4]	0.375	0.013	0.051	> 0.63	0.25	< 0.02	
Clethodim	0.25	0.008	1.34	11.4	0.006	< 0.0007	May pose hazard to federally listed endangered plants.
Diuron	2.4	0.081	0.0024	0.095	**30**	0.85	
EPTC	3.9	0.131	1.36	41	0.097	0.003	
Hexazinone	1.5	0.051	0.0068	0.21	7.4	0.2	
Imazamox	0.047	0.002	0.011	> 0.038	0.14	< 0.042	
Imazethapyr	0.094	0.003	0.0081	59.2	0.4	0.00005	
Metribuzin	1	0.034	0.008	0.16	**4.2**	0.21	
Norflurazon	0.98	0.033	0.0097	0.058	**3.4**	0.57	
Paraquat	0.8	0.027	0.00055	2.84	**50**	0.009	
Pronamide	2	0.067	0.76	> 4	0.09	< 0.017	
Sethoxydim	0.47	0.016	>0.27	5.6	<0.059	0.003	Toxic to aquatic organisms.
Terbacil	1.2	0.040	0.011	0.14	**3.7**	0.29	
Trifluralin	2	0.067	0.015	5	**4.5**	0.01	

NA = information not available or not applicable.

[1] EEC refers to the Estimated Environmental Concentration, which that a one-acre pond, six feet deep receives 5% drift from a one-acre field and 5% runoff from a 10-acre field.

[2] Aquatic EC50 values obtained from the 2010 EPA Ecotoxicology One-Liner, unless Footnote 4 is indicated.

[3] Risk Quotient is EEC/EC50. Risk Quotient **Bolded** if > 1.0 = Level of Concern [criteria from EPA Ecological Effects, Rejection Analysis].

[4] Toxicity values obtained from the available Reregistration Eligibility Documents, United States Environmental Protection Agency.

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4.9 CUMULATIVE IMPACTS ON HUMAN HEALTH AND SAFETY

Where pesticides may be used on food or feed crops, EPA sets tolerances (maximum pesticide residue levels) for the amount of the pesticide residues that can legally remain in or on foods. EPA undertakes this analysis under the authority of the Federal Food, Drug, and Cosmetic Act (FFDCA). Under the FFDCA, EPA must find that such tolerances will be safe, meaning that there is a reasonable certainty that no harm will result from aggregate exposure to the pesticide chemical residue. This finding must be made and the appropriate tolerance established before a pesticide can be registered for use on the particular food or feed crop in question (USDA APHIS, 2009).

Another potential impact of the use of glyphosate on human health is pesticide applicator exposure related to the increased glyphosate usage. Biomonitoring of pesticide applicators conducted by independent investigators has shown that bodily adsorption of glyphosate as the result of routine, labeled applications of registered glyphosate-based agricultural herbicides to crops, including to RRA, was thousands of times less than the allowable daily intake level established for glyphosate (Acquavella et al., 2004). Given similarity in use pattern and rates, the commercialization of RRA will not significantly increase the exposure risk to pesticide applicators. Furthermore, EPA, the European Commission, the WHO, and independent scientists have concluded that glyphosate is not mutagenic or carcinogenic, not a teratogen nor a reproductive toxicant, and that there is no evidence of neurotoxicity associated with glyphosate (EPA, 1993; EC, 2002; WHO, 2004; Williams et al., 2000).

Bystander exposure to glyphosate as a result of pesticide application to RRA would be negligible, since such applications would occur in an agricultural setting in relatively rural alfalfa fields, not in an urban setting. A biomonitoring study found little evidence of detectable exposure to individuals on the farm who were not actively involved with or located in the immediate vicinity of application of glyphosate-based herbicides to crops (Acquavella et al., 2004) Considering the similarity of the use pattern and application rates of the glyphosate products in this study compared to those registered for use on RRA and GT crops in general, bystander exposure attributed to the use of glyphosate on GT crops is expected to be negligible.

4.10 CUMULATIVE SOCIAL AND ECONOMIC IMPACTS

As discussed above in Sec. 3.15, the potential for gene flow from RRA seed acreage to conventional or organic alfalfa could have an adverse economic impact on conventional or organic growers who expect to receive a premium for their crops in markets that demand non-

RRA products. The partial deregulation measures proposed in Alternative 2, including isolation distances associated with seed production, are specifically designed to render the risk of any such impacts de minimis. Moreover, the reproductive biology of the alfalfa plant combined with normal harvest management for alfalfa forage provide for a de minimis likelihood of gene flow from one forage production field to another. Those producing organic or non-GE hay are likely required to maintain cultivation standards required by the NOP or identity preservation contracts that provide additional assurances against gene flow. While some of these growers may enter into contractual agreements that require testing for the presence of GE plant material, those tests are simple and inexpensive. Hay failing to meet contractual standards may still be sold as commodity hay.

It is anticipated that growers who plant RRA under Alternative 2 will experience economic benefits related to the quantity and improved forage quality of U.S. hay supplies. Growers have reported other socio-economic benefits, including greater flexibility, safety, ease and simplicity of weed control. APHIS has studied the potential socioeconomic impacts of fully deregulating RRA (USDA APHIS, 2009, pp. 125-145 & Appendix S).

4.11 SUMMARY OF POTENTIAL CUMULATIVE IMPACTS

When considering the impact that the use of glyphosate could have on the human environment in conjunction with other GT crops already being cultivated in the same affected environments, the facts suggest that increased use of glyphosate on acreage that shifts from conventional or organic alfalfa production to RRA production will have little, if any, additive effect. Alternatively, this new use of glyphosate has the potential to reduce risks to the affected environment from the use of other, more harmful, herbicides on these limited acreages. This is supported by the assessment of the hazards associated with glyphosate when compared to other available herbicides used for weed control in alfalfa production. Subsequently, there is no reasonably anticipated adverse cumulative impact on human health or the environment from the use of glyphosate associated specifically with Alternative 2.

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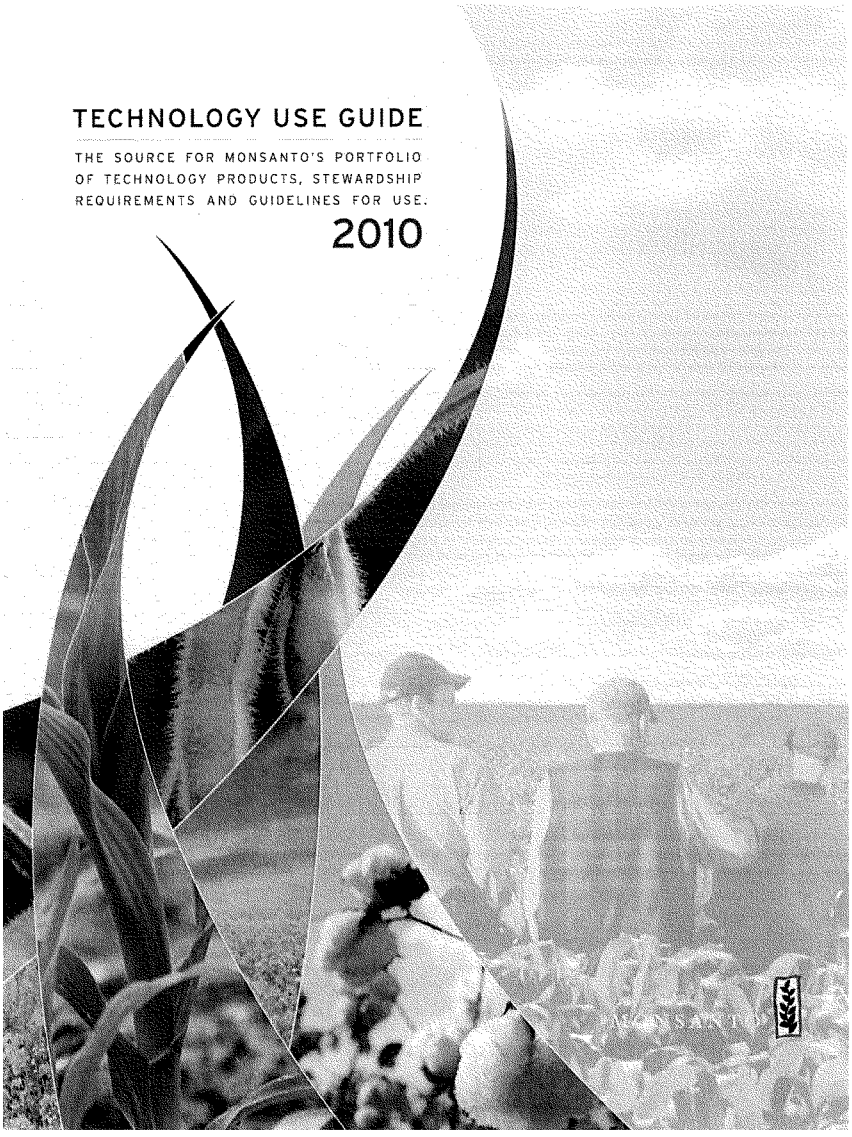
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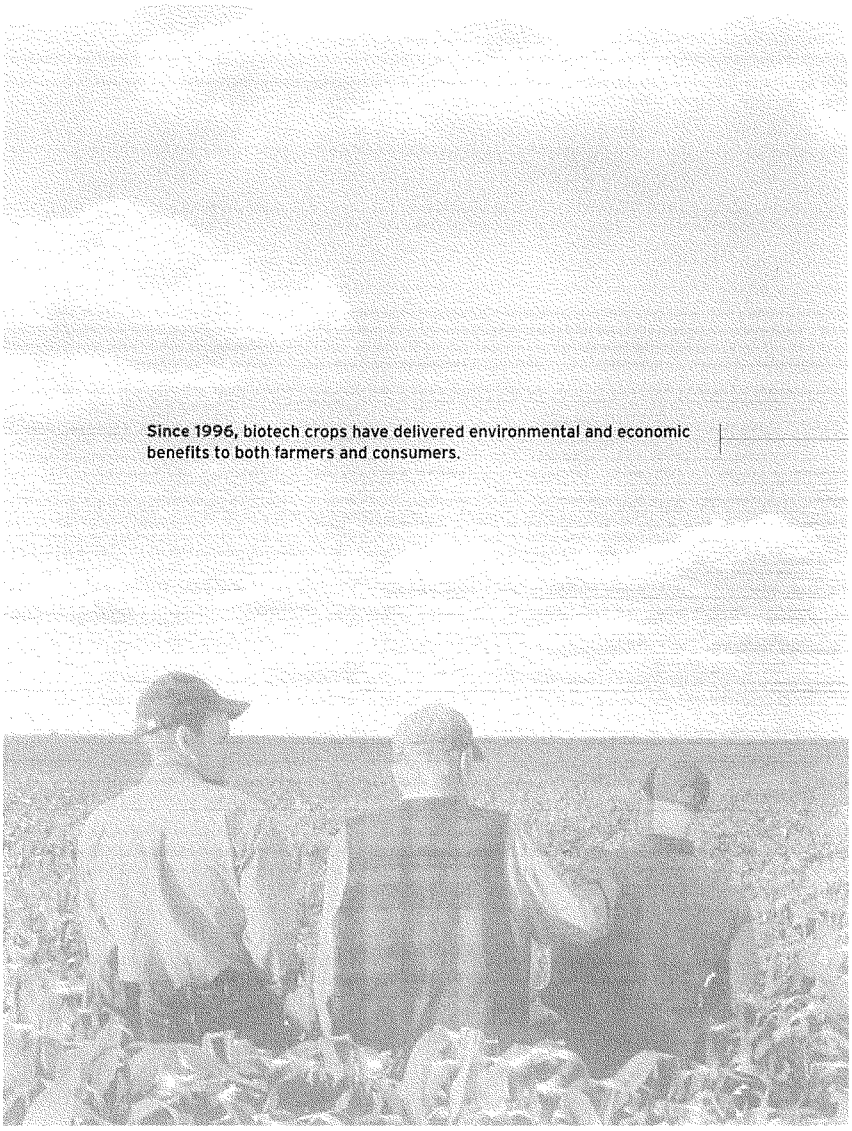
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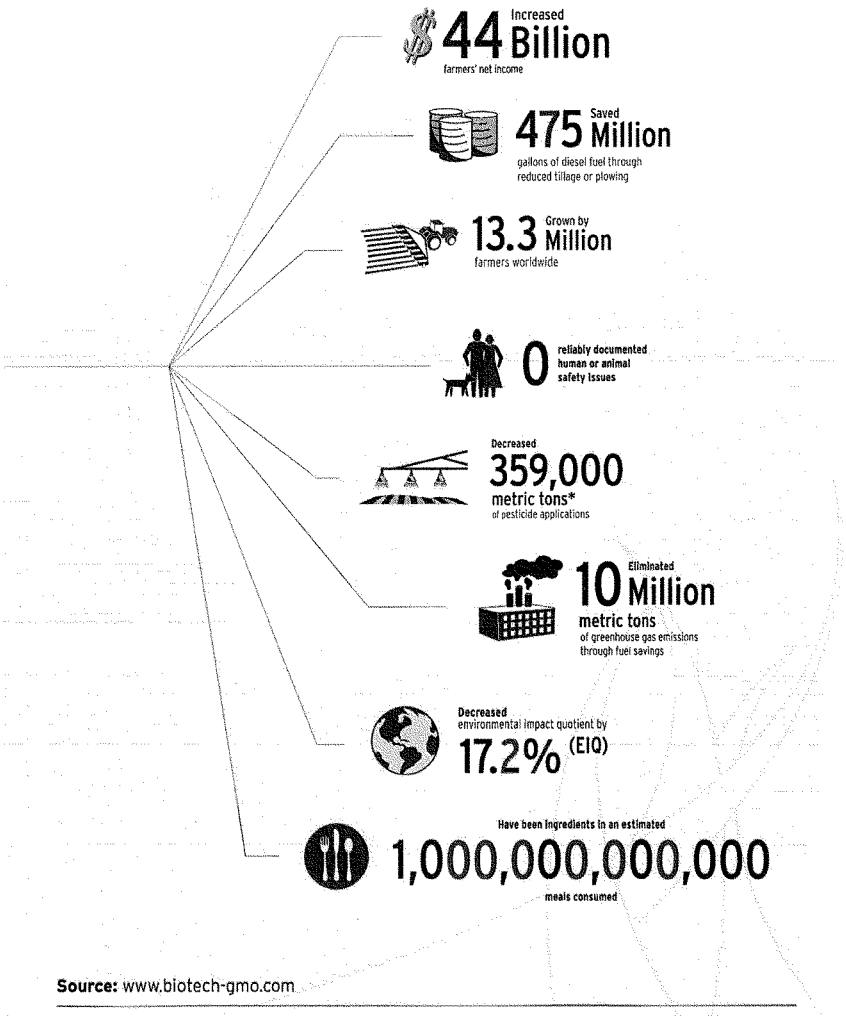
Appendix A

Monsanto Technology and Stewardship Agreement
(MT/SA)
and Accompanying Technology Use Guide (TUG)


TECHNOLOGY USE GUIDE
THE SOURCE FOR MONSANTO'S PORTFOLIO OF TECHNOLOGY PRODUCTS, STEWARDSHIP REQUIREMENTS AND GUIDELINES FOR USE.
2010



Since 1996, biotech crops have delivered environmental and economic benefits to both farmers and consumers.



Source: www.biotech-gmo.com

*Pesticides registered by the U.S. EPA will not cause unreasonable adverse effects to man or the environment when used in accordance with label directions.

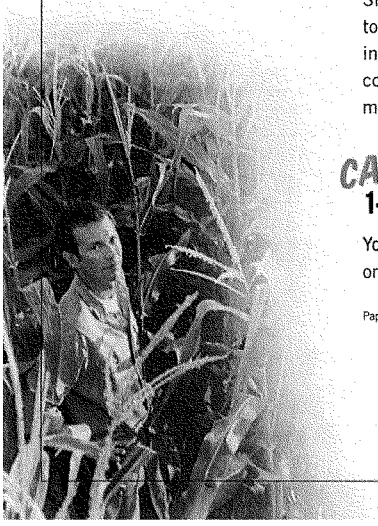
RE:NEW

YOUR ABILITY TO ENHANCE YOUR CROPS TODAY!

It's time to ReNEW your license

If you haven't renewed your Monsanto Technology/Stewardship Agreement (MTSA) in the past nine months, **take care of it today!**

Signing the MTSA ensures you'll have access to current and next-wave technologies. These innovations will enhance plant drought tolerance, cold tolerance, nitrogen use efficiency, yield and much more!



CALL

1-800-768-6387, Option 3

You'll then have the option to complete the process online or through conventional mail.

Paper MTSA's will continue to be accepted.

Introduction

This 2010 Technology Use Guide (TUG) provides a concise source of technical information about Monsanto's current portfolio of technology products and sets forth requirements and guidelines for the use of these products. As a user of Monsanto Technology, it is important that you are familiar with and follow certain management practices. Please read all of the information pertaining to the technology you will be using, including stewardship and related information. Growers must read the Insect Resistance Management (IRM)/Grower Guide prior to planting for important information on planting and IRM.

This technical guide is not a pesticide product label. It is intended to provide additional information and to highlight approved uses from the product labeling. Read and follow all precautions and use instructions in the label booklet and separately published supplemental labeling for the Roundup® agricultural herbicide product you are using.

Included in this guide is information on the following:

Stewardship Overview	4
Introducing Genuity™	6
Insect Resistance Management	8
Weed Management	10
Coexistence and Identity Preserved Production	12
Corn Technologies	15
YieldGard® and Genuity™ Corn Technologies Product Descriptions	
Roundup Ready® Technology in Corn	
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Genuity™ Bollgard II® and Bollgard® Cotton	
Roundup Ready Technologies in Cotton	
Genuity™ Roundup Ready 2 Yield® and Roundup Ready Soybeans	31
Genuity™ Roundup Ready® Alfalfa	35
Genuity™ Roundup Ready® Spring Canola	38
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If you have any questions, contact your Authorized Retailer or Monsanto at 1-800-768-6387.

A Message About Stewardship - SEED AND TRAITS

Monsanto Company is committed to enhancing farmer productivity and profitability through the introduction of new agricultural biotechnology traits. These new technologies bring enhanced value and benefits to farmers, and farmers assume new responsibilities for proper management of these traits. Farmers planting seed with biotech traits agree to implement good stewardship practices, including, but not limited to:

- Reading, signing and complying with the Monsanto Technology/Stewardship Agreement (MTSA) and reading all annual license terms updates before purchase or use of any seed containing a trait.
- Reading and following the directions for use on all product labels.
- Following applicable stewardship practices as outlined in this TUG.
- Reading and following the IRM/Grower Guide prior to planting.
- Observing regional planting restrictions mandated by the U.S. Environmental Protection Agency (EPA).
- Complying with any additional stewardship requirements, such as grain or feed use agreements or geographical planting restrictions, that Monsanto deems appropriate or necessary to implement for proper stewardship or regulatory compliance.
- Following the Weed Resistance Management Guidelines to minimize the risk of resistance development.
- Complying with the applicable IRM practices for specific biotech traits as *mandated* by the EPA and set forth in this TUG.
- Utilizing all seed with biotech traits only for planting a single crop.
- Selling crops or material containing biotech traits only to grain handlers that confirm their acceptance, or using those products on farm.
- Not moving material containing biotech traits across boundaries into nations where import is not permitted.
- Not selling, promoting and/or distributing within a state where the product is not yet registered.

CROP OR MATERIAL HANDLING STEWARDSHIP STATEMENT

Monsanto Company is a member of Excellence Through Stewardship® (ETS). Monsanto products are commercialized in accordance with ETS Product Launch Stewardship Guidance, and in compliance with Monsanto's Policy for Commercialization of Biotechnology-Derived Plant Products in Commodity Crops. This product has been approved for import into key export markets with functioning regulatory systems. Any crop or material produced from this product can only be exported to, or used, processed or sold in countries where all necessary regulatory approvals have been granted. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Growers should talk to their grain handler or product purchaser to confirm their buying position for this product. Excellence Through Stewardship® is a registered trademark of Biotechnology Industry Organization.

WHY IS STEWARDSHIP IMPORTANT?

Each component of stewardship offers benefits to farmers:

- Signing the MTSA provides farmers access to Monsanto's biotech trait seed technology.
- Following IRM guidelines guards against insect resistance to *Bacillus thuringiensis (B.t.)* technology and therefore enables the long-term viability of this technology, and meets EPA requirements.
- Proper weed management maintains the long-term effectiveness of glyphosate-based weed control solutions.
- Utilizing biotech seed only for planting a single-commercial crop helps preserve the effectiveness of biotech traits, while allowing investment for future biotech innovations which further improves farming technology and productivity.

Practicing these stewardship activities will enable biotechnology's positive agricultural contributions to continue.

Farmers' attitudes and adoption of sound stewardship principles, coupled with biotechnology benefits, provide for the sustainability of our land resources, biotechnology and farming as a preferred way of life.

SEED PATENT INFRINGEMENT

If Monsanto reasonably believes that a farmer has planted saved seed containing a Monsanto biotech trait, Monsanto will request invoices and records to confirm that fields in question have been planted with newly purchased seed. If this information is not provided within 30 days, Monsanto may inspect and test all of the farmer's fields to determine if saved seed has been planted. Any inspections will be coordinated with the farmer and performed at a reasonable time to best accommodate the farmer's schedule.

If you have questions about seed stewardship or become aware of individuals utilizing biotech traits in a manner other than as noted above, please call 1-800-768-6387. Letters reporting unacceptable or unauthorized use of biotech traits may be sent to:

Monsanto Trait Stewardship
800 N. Lindbergh Boulevard NC3C
St. Louis, MO 63167

For more information on Monsanto's practices related to seed patent infringement, please visit: www.monsanto.com/seedpatentprotection.

Provide Anonymous or Confidential reports as follows:

"Anonymous" reporting results when a person reports information to Monsanto in such a way that the identity of the person reporting the information cannot be identified. This kind of reporting includes telephone calls requesting anonymity and unsigned letters.

"Confidential" reporting results when a person reports information to Monsanto in such a way that the reporting person's identity is known to Monsanto. Every effort will be made to protect a person's identity, but it is important to understand that a court may order Monsanto to reveal the identity of people who are "known" to have supplied relevant information.



The Beyond the Seed Program was launched by the American Seed Trade Association (ASTA) to raise awareness and understanding of the value that goes beyond the seed. The future success of U.S. agriculture depends upon quality seed delivered by an industry commitment to bring innovation and performance through continued investment. For more information about seed technology, visit ASTA's Beyond the Seed Program at www.beyondtheseed.org.

Genuity™ Unites the Best Traits*

As a purchaser of Monsanto biotech trait products, your investment helps fuel the research and development engine that leads to the discovery and delivery of new technologies for agriculture. Current and future Genuity™ traits are designed to deliver high yield potential, maximize return on seed investments and consistently deliver future trait innovations.

CORN

Higher yields come from quality grain. Genuity™ VT Triple PRO™ was the next generation of corn technology available for the 2009 growing season. Genuity™ VT Triple PRO™ provides dual modes of action against above-ground pests such as corn earworm, European and southwestern corn borers, sugarcane borer, southern cornstalk borer and fall armyworm. Reduced kernel damage from corn earworm means the potential for reduced Aflatoxin contamination. Genuity™ VT Triple PRO™ dual modes-of-action also allows for a reduction in refuge acres required in southern cotton-growing regions while providing long-term effectiveness and consistency.

GENUITY™ SMARTSTAX™

Scheduled for launch in 2010, Genuity™ SmartStax™ is the most-advanced, all-in-one corn trait system that controls the broadest spectrum of above- and below-ground insects and weeds. Genuity™ SmartStax™ provides control of corn earworm, European corn borer, southwestern corn borer, sugarcane borer, fall armyworm, western bean cutworm, black cutworm, western corn rootworm, northern corn rootworm and Mexican corn rootworm. Genuity™ SmartStax™ contains Roundup Ready® 2 Technology and LibertyLink® herbicide tolerance. Genuity™ SmartStax™ also allows for a reduction in refuge acres in the corn belt from 20% down to 5% for above- and below-ground refuge. Genuity™ SmartStax™ is also approved for a 20% refuge in the cotton belt.

SOYBEAN

Genuity™ Roundup Ready 2 Yield® soybeans are taking yield to a higher level. They were developed to provide farmers with the same simple, dependable and flexible weed control and crop safety they've come to rely on with the first-generation Roundup Ready® soybean system, but with higher yield potential. This is possible because of advanced insertion and selection technologies.

COTTON

Genuity™ Roundup Ready® Flex and Genuity™ Bollgard II® offer the ultimate combination of peace of mind and flexibility. They contain unrivaled built-in worm control to stop the most leaf- and boll-feeding worm species, including bollworms, budworms, armyworms, loopers, saltmarsh caterpillars and cotton leaf perforators. Protecting just one additional boll per plant can result in significantly higher lint yield. The convenience and savings from fewer or no sprays for worms can make a big difference when it comes to the bottom line.

SPECIALTY

Genuity™ Roundup Ready® alfalfa: Bred from an innovative germplasm pool, it offers outstanding weed control, excellent crop safety and preservation of forage quality potential.

Genuity™ Roundup Ready® canola: Offers excellent control of broadleaf weeds and grasses, even in tough weather conditions. Also features excellent crop safety and broad application flexibility.

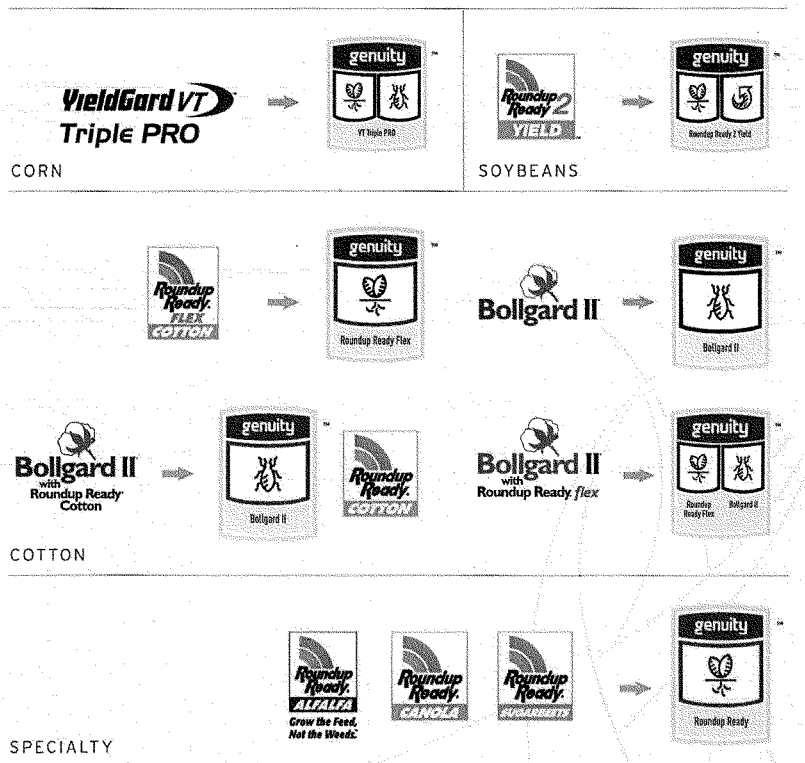
Genuity™ Roundup Ready® sugarbeets: Excellent in-plant tolerance to over-the-top applications of labeled Roundup agricultural herbicides. Offers outstanding weed control, excellent crop safety and preservation of yield potential.

*See pages 16 and 17 for additional traits.

NOTE: Farmers must read the IRM/Grower Guide prior to planting for information on planting and Insect Resistance Management.

Monsanto's New Generation of Technologies

As Monsanto continues to develop new generations of technologies, several of our newer technologies are migrating to the Genuity™ brand. These products and their new logos are presented below.



INSECT RESISTANCE MANAGEMENT (IRM)



An **EFFECTIVE** IRM program is a vital part of responsible product stewardship for insect-protected biotech products. Monsanto is committed to implementing an effective IRM program for all of its insect-protected *B.t.* technologies in all countries where they are commercialized, including promoting farmer awareness of these IRM programs. Monsanto works to develop and implement IRM programs that strike a balance between available knowledge and practicality, with farmer acceptance and implementation of the plan as critical components.

The U.S. EPA requires that Monsanto implement, and farmers who purchase insect-protected products follow, an IRM plan.* IRM programs for *B.t.* traits are based upon an assessment of the biology of the major target pests, farmer needs and practices, and appropriate pest management practices. These **mandatory regulatory programs** have been developed and updated through broad cooperation with farmer and consultant organizations, including the National Corn Growers Association and the National Cotton Council, extension specialists, academic scientists, and regulatory agencies.

*In some areas, a natural refuge option is available for Bollgard II. See the current IRM/Grower Guide for details.

The IRM programs for planting seeds containing *B.t.* traits contain several important elements. One key component of an IRM plan is a refuge. A refuge is simply a portion of the relevant crop (corn or cotton) that does not contain a *B.t.* technology for the control of the insect pests which are controlled by the planted technology(ies). The lack of exposure to the *B.t.* proteins means that there will be susceptible insects nearby to mate with any rare resistant insects that may emerge from *B.t.* products. Susceptibility to *B.t.* products is then passed on to offspring, preserving the long-term effectiveness of the technology.

Farmers who purchase seeds containing *B.t.* traits must plant an appropriately designed refuge. Refuge size, configuration, and management is described in detail in the sections on those products in the 2010 IRM/Grower Guide.

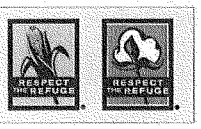
Failure to follow IRM requirements and to plant a proper refuge may result in the loss of a farmer's access to Monsanto technologies. Monsanto is committed to the preservation of *B.t.* technologies. Please do your part to preserve *B.t.* technologies by implementing the correct IRM plan on your farm.

MONITORING PROGRAM

The U.S. EPA requires Monsanto to take corrective measures in response to a finding of IRM non-compliance. Monsanto or an approved agent of Monsanto must monitor refuge management practices. The MTSA signed by a farmer requires that upon request by Monsanto or its approved agent, a farmer must provide the location of all fields planted with Monsanto technologies and the locations of all associated refuge areas as **required**, to cooperate fully with any field inspections, and allow Monsanto to inspect all fields and refuge areas to ensure an approved insect resistance program has been followed. All inspections will be performed at a reasonable time and arranged in advance with the farmer so that the farmer can be present if desired.

IRM GUIDELINES

Farmers must read the current IRM/Grower Guide prior to planting for information on planting and IRM. If you do not have a copy of the current IRM/Grower Guide, you may downloaded it at www.monsanto.com, or you may call 1-800-768-6387 to request a copy by mail.



WEED MANAGEMENT

Monsanto considers product stewardship to be a fundamental component of customer service and responsible business practices. As leaders in the development and stewardship of Roundup® agricultural herbicides and other products, Monsanto invests significantly in research to continuously improve the proper uses and stewardship of our proprietary herbicide brands.

This research, done in conjunction with academic scientists, extension specialists and crop consultants, includes an evaluation of the factors that can contribute to the development of weed resistance and how to properly manage weeds to delay the selection for weed resistance. Visit **www.weedtool.com** for practical, best practices-based information on reducing the risk for development of glyphosate-resistant weeds. Developed in cooperation with academic experts, the website provides options for managing the risk on a field-by-field basis.

Glyphosate is a Group 9 herbicide based on the mode of action classification system of the Weed Science Society of America. Any weed population may contain plants naturally resistant to Group 9 herbicides. The following general recommendations help manage the risk of weed resistance occurring.

WEED RESISTANCE MANAGEMENT PRACTICES:

- Scout your fields before and after herbicide application
- Start with a clean field, using either a burndown herbicide application or tillage
- Control weeds early when they are small
- Add other herbicides (e.g. a selective in-crop and/or a residual herbicide) and cultural practices (e.g. tillage or crop rotation) as part of your Roundup Ready® cropping system where appropriate
- Rotation to other Roundup Ready crops will add opportunities for introduction of other modes of action
- Use the right herbicide product at the right rate and the right time
- Control weed escapes and prevent weeds from setting seeds
- Clean equipment before moving from field to field to minimize spread of weed seed
- Use new commercial seed that is as free from weed seed as possible

Monsanto is committed to the proper use and long-term effectiveness of its proprietary herbicide brands through a four-part stewardship program: developing appropriate weed control recommendations, continuing research to refine and update recommendations, education on the importance of good weed management practices and responding to repeated weed control inquiries through a product performance evaluation program.

GLYPHOSATE-RESISTANT WEEDS

Monsanto actively investigates and studies weed control complaints and claims of weed resistance. When glyphosate-resistant weed biotypes have been confirmed, Monsanto alerts farmers and develops and provides farmers with recommended control measures, which may include additional herbicides, tank-mixes or cultural practices. Monsanto actively communicates all of this information to farmers through multiple channels, including the herbicide label, **www.weedscience.org**, supplemental labeling, this TUG, media and written communications, Monsanto's website, **www.weedresistancemanagement.com**, and farmer meetings.

Farmers must be aware of, and proactively manage for, glyphosate-resistant weeds in planning their weed control program. When a weed is known to be resistant to glyphosate, then a resistant population of that weed is by definition no longer controlled with labeled rates of glyphosate. Roundup® agricultural herbicide warranties will not cover the failure to control glyphosate-resistant weed populations.

Report any incidence of repeated non-performance on a particular weed to your local Monsanto representative, retailer or county extension agent.

Note: Always read and follow all pesticide label requirements.

ROUNDUP BRAND AGRICULTURAL OVER-THE-TOP HERBICIDE PRODUCTS

Read and follow all product labeling before using Roundup agricultural herbicides over the top of products with Roundup Ready Technology.

You may use another glyphosate herbicide, but only if it has federally approved label instructions for use over that specific Roundup Ready crop, and the product and the use label for that Roundup Ready crop has been approved by your specific state. Contact the product manufacturers, the local retailers or the local extension agents for confirmation that the products carry EPA and state approved labeling for this use. **MONSANTO DOES NOT MAKE ANY REPRESENTATIONS, WARRANTIES OR RECOMMENDATIONS CONCERNING THE USE OF GLYPHOSATE PRODUCTS SUPPLIED BY OTHER COMPANIES WHICH ARE LABELED FOR USE OVER ROUNDUP READY CROPS. MONSANTO SPECIFICALLY DENIES ALL RESPONSIBILITY AND DISCLAIMS ANY LIABILITY FOR ANY DAMAGE FROM THE USE OF THESE PRODUCTS IN ROUNDUP READY CROPS. ALL QUESTIONS AND COMPLAINTS CAUSED BY THE USE OF GLYPHOSATE PRODUCTS SUPPLIED BY OTHER COMPANIES SHOULD BE DIRECTED TO THE SUPPLIER OF THE PRODUCT IN QUESTION.**

MONSANTO BRANDS OF SELECTIVE OVER-THE-TOP HERBICIDE PRODUCTS

Herbicide products sold by Monsanto for use over the top of Roundup Ready crops for the 2010 crop season are as follows:

Roundup WeatherMAX®

Roundup PowerMAX®

Read and follow all product labeling before using Roundup agricultural herbicides over the top of Roundup Ready traits. To learn more about applicable supplemental labels or fact sheets, call 1-800-768-6387.

Tank-mixtures of Roundup agricultural herbicides with insecticides, fungicides, micronutrients or foliar fertilizers are not recommended as they may result in reduced weed control, crop injury, reduced pest control or antagonism. Refer to the Roundup agricultural herbicide product label, supplemental labeling or fact sheets published separately by Monsanto for tank-mix recommendations.

Do not add additional surfactants and/or products containing surfactants to these Roundup agricultural herbicides unless otherwise directed by the label. Other glyphosate products labeled for use in Roundup Ready technologies may require the addition of surfactants, or other additives to optimize performance, that may increase the potential for crop injury. Monsanto will label and promote only fully tested brands that do not require surfactants and other additives for over-the-top applications to Roundup Ready Crops.

GLYPHOSATE ENDANGERED SPECIES INITIATIVE

Before making applications of glyphosate-based herbicide products, licensed farmers of crops containing Roundup Ready technology must access the website **www.pre-serve.org** to determine whether any mitigation requirements apply to the planned application to those crops, and must follow all applicable requirements. The mitigation measures described on the website are appropriate for all applications of glyphosate-based herbicides to all crop lands.

Farmers making only ground applications to crop land with a use rate of less than 3.5 lbs of glyphosate a.e./A are not required to access the website. If a farmer does not have web access, the seed dealer can access the website on behalf of the farmer to determine the applicable requirements, or the farmer can call 1-800-332-3111 for assistance.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS IN ROUNDUP READY CROPS

In certain areas, populations of ryegrass, johnsongrass, marestail, common ragweed, giant ragweed, *Palmer Amaranth* and waterhemp are known to be resistant to glyphosate. For control recommendations for resistant biotypes of these weeds, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net** or obtained by calling 1-800-768-6387.

COEXISTENCE AND IDENTITY PRESERVED PRODUCTION

Coexistence in agricultural production systems and supply chains is not new. Different agricultural systems have coexisted successfully for many years around the world. Standards and best practices were established decades ago and have continually evolved to deliver high purity seed and grain to support production, distribution and trade of products from different agricultural systems. For example, production of similar commodities such as field corn, sweet corn and popcorn has occurred successfully and in close proximity for many years. Another example is the successful coexistence of oilseed rape varieties with low erucic acid content for food use and high erucic acid content for industrial uses.

The introduction of biotech crops generated renewed discussion of coexistence focused on biotech production systems with conventional cropping systems and organic production. These discussions have primarily focused on the potential economic impact of the introduction of biotech products on other systems. The health and safety of biotech products are not an issue because their food, feed and environmental safety must be demonstrated before they enter the agricultural production system and supply chain.

The coexistence of conventional, organic and biotech crops has been the subject of several studies and reports. These reports conclude that coexistence among biotech and non-biotech crops is not only possible but is occurring. They recommend that coexistence strategies be developed on a case-by-case basis considering the diversity of products currently in the market and under development, the agronomic and biological differences in the crops themselves and variations in regional farming practices and infrastructures. Furthermore, coexistence strategies are driven by market needs and should be developed using current science-based industry standards and management practices. The strategies must be flexible, facilitating options and choice for the farmer and the food/feed supply chain, and must be capable of being modified as changes in markets and products warrant.

Successful coexistence of all agricultural systems is achievable and depends on cooperation, flexibility and mutual respect for each system. Agriculture has a history of innovation and change, and farmers have always adapted to new approaches or challenges by utilizing appropriate strategies, farm management practices and new technologies.

The responsibility for implementing practices to satisfy specific marketing standards or certification lies with that farmer who is growing a crop to satisfy a particular market. Only that farmer is instructed to employ the practices appropriate to assure the integrity of his/her crop. This is true whether the goal is high-oil corn, white/sweet corn or organically produced yellow corn for animal feed. In each case, the farmer is seeking to produce a crop that is supported by a market price and consequently that farmer assumes responsibility for satisfying reasonable market specifications. That said, the farmer needs to be aware of the planting intentions of his/her neighbor in order to gauge the need for management practices.

IDENTITY PRESERVED PRODUCTION

Some farmers may choose to preserve the identity of their crops to meet specific markets. Examples of Identity Preserved (I.P.) corn crops include production of seed corn, white, waxy or sweet corn, specialty oil or protein crops, food grade crops and any other crop that meets specialty needs, including organic and non-genetically enhanced specifications. Farmers of these crops assume the responsibility and receive the benefit for ensuring that their crop meets mutually agreed contract specifications.

Based on historical experience with a broad range of I.P. crops, the industry has developed generally accepted I.P. agricultural practices. These practices are intended to manage I.P. production to meet quality specifications, and are established for a broad range of I.P. needs. The accepted practice with I.P. crops is that each I.P. farmer has the responsibility to implement any necessary processes. These processes may include sourcing seed appropriate for I.P. specifications, field management practices such as adequate isolation distances, buffers between crops, border rows, planned differences in maturity between adjacent fields that might cross-pollinate and harvest and handling practices designed to prevent mixing and to maintain product quality. These extra steps associated with I.P. crop production are generally accompanied by incremental increases in cost of production and consequently of the goods sold.

General Instructions for Management of Pollen Flow and Mechanical Mixing

For all crop hybrids or varieties that they wish to identity preserve, or otherwise keep separated, farmers should take steps to prevent mechanical mixing. Farmers should make sure all seed storage areas, transportation vehicles and planter boxes are cleaned thoroughly both prior to and subsequent to the storage, transportation or planting of the crop. Farmers should also make sure all combines, harvesters and transportation vehicles used at harvest are cleaned thoroughly both prior to and subsequent to their use in connection with the harvest of the grain produced from the crop. Farmers should also make sure all harvested grain is stored in clean storage areas where the identity of the grain can be preserved.

Self-pollinated crops, such as soybeans, do not present a risk of mixing by cross-pollination. If the intent is to use or market the product of a self-pollinated crop separately from general commodity use, farmers should plant fields a sufficient distance away from other crops to prevent mechanical mixture.

Farmers planting cross-pollinated crops, such as corn or alfalfa, who desire to preserve the identity of these crops, or to minimize the potential for these crops to outcross with adjacent fields of the same crop kind, should use the same generally accepted practices to manage mixing that are used in any of the currently grown I.P. crops of similar crop kind.

It is generally recognized in the industry that a certain amount of incidental, trace level pollen movement occurs, and it is not possible to achieve 100% purity of seed or grain in any corn production system. A number of factors can influence the occurrence and extent of pollen movement. As stewards of technology, farmers are expected to consider these factors and talk with their neighbors about their cropping intentions.

Farmers should take into account the following factors that can affect the occurrence and extent of cross-pollination to or from other fields. Information that is more specific to the crop and region may be available from state extension offices.

- Cross-pollination is limited. Some plants, such as potatoes, are incapable of cross-pollinating, while others, like alfalfa, require cross-pollination to produce seed, importantly, cross-pollination only occurs within the same crop kind, like corn to corn.
- The amount of pollen produced within the field can vary. The pollen produced by the crop within a given field, known as pollen load, is typically high enough to pollinate all of the plants in the field. Therefore, most of the pollen that may enter from other fields falls on plants that have already been pollinated with pollen that originated from plants within the field. In crops such as alfalfa, the hay cutting management schedule significantly limits or eliminates bloom, and thereby restricts the potential for pollen and/or viable seed formation.
- The existence and/or degree of overlap in the pollination period of crops in adjacent fields varies. This will vary depending on the maturity of crops, planting dates and the weather. For corn, the typical pollen shed period lasts from 5 to 10 days for a particular field. Therefore, viable pollen from neighboring fields must be present when silks are receptive in the recipient field during this brief period to produce any grain with traits introduced by the out-of-field pollen.
- Distance between fields of different varieties or hybrids of the same crop: The greater the distance between fields the less likely their pollen will remain viable and have an opportunity to mix and produce an outcross. For wind-pollinated crops, most cross-pollination occurs within the outermost few rows of the field. In fact, many white and waxy corn production contracts ask the farmer to remove the outer 12 rows (30 ft.) of the field in order to remove most of the impurities that could result from cross-pollination with nearby yellow dent corn. Furthermore, research has also shown that as fields become further separated, the incidence of wind-modulated cross-pollination drops rapidly. Essentially, the in-field pollen has an advantage over the pollen coming from other fields for receptive silks because of its volume and proximity to silks.
- The distance pollen moves. How far pollen can travel depends on many environmental factors, including weather during pollination, especially wind direction and velocity, temperature and humidity. For bee-pollinated crops, the farmer's choice of pollinator species and apiary management practice may reduce field-to-field pollination potential. All these factors will vary from season to season, and some factors from day to day and from location to location.
- For wind-pollinated crops, the orientation and width of the adjacent field in relation to the dominant wind direction. Fields oriented upwind during pollination will show dramatically lower cross-pollination for wind-pollinated crops, like corn, compared to fields located downwind.



Advanced breeding and biotechnology have had a major impact on farming production. From 1971 to 1995, average corn yields were increasing at a rate of 1.5 bushels per acre, per year. Since the advent of biotech in 1996, corn yields have increased at a rate of 2.6 bushels per acre, per year, for a total increase of 32 bushels per acre.*

Excellence Through Stewardship

Monsanto Company is a member of Excellence Through Stewardship® (ETS). Monsanto products are commercialized in accordance with ETS Product Launch Stewardship Guidance, and in compliance with Monsanto's Policy for Commercialization of Biotechnology-Derived Plant Products in Commodity Crops. This product has been approved for import into key export markets with functioning regulatory systems. Any crop or material produced from this product can only be exported to, or used, processed or sold in countries where all necessary regulatory approvals have been granted. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Growers should talk to their grain handler or product purchaser to confirm their buying position for this product. Excellence Through Stewardship® is a registered trademark of Biotechnology Industry Organization.

IRM GUIDELINES

For specific refuge requirements for *B.t.* corn and cotton, see the current IRM/Grower Guide, sent with this TUG. If you have not received a copy of this Guide, it can be downloaded at www.monsanto.com, or call 1-800-768-6387 to request a copy be mailed to you.





Before opening a bag of seed, be sure to read and understand the stewardship requirements, **including applicable refuge requirements for insect resistance management,** for the biotechnology traits expressed in the seed as set forth in the Monsanto Technology Agreement that you sign. By opening and using a bag of seed, you are reaffirming your obligation to comply with those stewardship requirements.

* USDA Yields were calculated using 3 year rolling averages (32 Yield is 2.6 bu/ac *12 years). 2008 Yield is from Doane Ag Services forecast in April 8, 2008 Quarterly Crop Outlook.

Genuity™ Trait Products and YieldGard® Corn Technologies Product Descriptions

GENUITY™ SMARTSTAX™

Scheduled to launch in 2010, Genuity™ SmartStax™ is the most advanced, all-in-one corn trait system that controls the broadest spectrum of above- and below-ground insects and weeds. Genuity™ SmartStax™ hybrids will contain *B.t.* proteins that represent three separate modes of action for control of lepidopteron, above-ground insect pests, as well as combined modes of action for control of coleopteran, below-ground insect pests. Providing multiple *B.t.* proteins for control will dramatically decrease the probability that insects will become resistant to the traits, resulting in enhanced durability of transgenic insect control via *B.t.* genes. Based on this multiple gene approach, Genuity™ SmartStax™ is approved for reduced refuge in the corn belt from 20% down to 5% for both above- and below-ground pests. The cotton belt refuge for Genuity SmartStax™ is also reduced, from 50% down to 20%.

GENUITY™ VT TRIPLE PRO™

(Formerly YieldGard VT Triple PRO™) — Genuity™ VT Triple PRO™ is available in selected southern corn- and cotton-growing areas. It includes broad-spectrum insect control against corn earworm, European and southwestern corn borers, sugarcane borer, southern cornstalk borer, fall armyworm, western corn rootworm, northern corn rootworm and Mexican corn rootworm. Its advanced control of ear pests can result in higher grain quality and higher-yielding crop potential. The dual mode-of-action of Genuity™ VT Triple PRO™ allows for lower corn borer refuge acres in southern cotton-growing areas compared to other registered *B.t.*-traited products. It includes the same Roundup Ready® 2 Technology as Monsanto's previous product, YieldGard VT Triple. Seed containing Genuity™ VT Triple PRO™ technology is treated with seed-applied insecticide.*

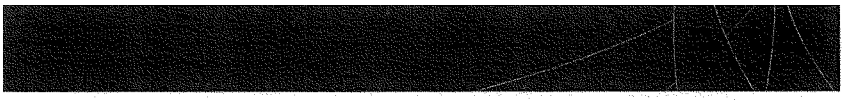
YIELDGARD VT TRIPLE®

YieldGard VT Triple technology combines YieldGard Corn Borer and YieldGard VT Rootworm/RR2® technology into a single plant. YieldGard VT Triple corn hybrids control European and southwestern corn borer, sugarcane borer, southern cornstalk borer, western corn rootworm, northern corn rootworm and Mexican corn rootworm. YieldGard VT Triple technology suppresses corn earworm, fall armyworm and stalk borer. By providing in-plant protection against the above insect pests, the genetic yield potential of YieldGard VT Triple corn hybrids is preserved. YieldGard VT Triple corn hybrids also include Roundup Ready 2 Technology. This trait allows a farmer to experience the benefits of utilizing Roundup agricultural herbicides in a weed control system that provides the broadest weed control spectrum available, better application flexibility, and superior crop safety. Seed containing YieldGard VT Triple technology is treated with seed-applied insecticide.*

GENUITY™ VT DOUBLE PRO™

Genuity™ VT Double PRO™ is a new corn technology scheduled for launch in 2010. It includes broad-spectrum insect control against corn earworm, European and southwestern corn borers, sugarcane borer, southern cornstalk borer and fall armyworm. The dual mode-of-action of Genuity™ VT Double PRO™ allows for lower corn borer refuge acres compared to other registered *B.t.*-traited products. Seed containing Genuity™ VT Double PRO™ technology is treated with seed-applied insecticide.*

*A seed-applied insecticide can protect seed, roots and seedlings from insects such as black cutworm, wireworm, white grubs, seed corn maggots, chinch bug and early flea beetles.



YieldGard VT Rootworm/RR2

YIELDGARD VT ROOTWORM/RR2®

YieldGard VT Rootworm/RR2 technology is the current YieldGard stacked-trait product for control of western corn rootworm, northern corn rootworm and Mexican corn rootworm. Protecting the root of the corn plant from feeding by corn rootworm larvae decreases lodging and protects the genetic yield potential of YieldGard VT Rootworm/RR2 corn hybrids. The Roundup Ready 2 Technology allows a farmer to experience the benefits of utilizing Roundup agricultural herbicides in a weed control system that provides the broadest weed control spectrum, better application flexibility and superior crop safety. Seed containing YieldGard VT Rootworm/RR2 technology is treated with seed-applied insecticide.*



YIELDGARD® CORN BORER

YieldGard Corn Borer corn hybrids contain an insecticidal protein from *B.t.* that protects corn plants from European corn borer, southwestern corn borer, sugarcane borer and southern cornstalk borer resulting in full yield potential.



YIELDGARD PLUS

YieldGard Plus corn technology combines YieldGard Corn Borer and YieldGard Rootworm technology into a single plan.



YIELDGARD ROOTWORM

YieldGard Rootworm corn hybrids contain an insecticidal protein from *B.t.* that protects corn roots from larval feeding by western, northern and Mexican corn rootworm.



YIELDGARD® CORN BORER WITH ROUNDUP READY® CORN 2

YieldGard Corn Borer with Roundup Ready Corn 2 offers farmers all the benefits of both traits combined in one crop. These hybrids exhibit the same insect protection qualities as YieldGard Corn Borer and, like Roundup Ready Corn 2, are tolerant to over-the-top applications of Roundup® agricultural herbicides.



YIELDGARD PLUS WITH ROUNDUP READY CORN 2

YieldGard Plus with Roundup Ready Corn 2 offers farmers all the benefits of all three traits combined in one crop. These hybrids exhibit the same insect protection qualities of YieldGard Corn Borer and YieldGard Rootworm and, like Roundup Ready Corn 2, are tolerant to over-the-top applications of Roundup® agricultural herbicides. Seed containing YieldGard Plus technology is treated with seed-applied insecticide.*



YIELDGARD ROOTWORM WITH ROUNDUP READY CORN 2

YieldGard Rootworm with Roundup Ready Corn 2 offers farmers all the same insect protection qualities as YieldGard Rootworm and, like Roundup Ready Corn 2, is tolerant to over-the-top applications of Roundup agricultural herbicides.

*A seed-applied insecticide can protect seed, roots and seedlings from insects such as black cutworm, wireworm, white grubs, seed corn maggots, chinch bug and early flea beetles.

ROUNDUP READY® Technology in Corn

WEED CONTROL RECOMMENDATIONS

Roundup Ready® Corn 2 (RR2) and corn with Roundup Ready® 2 Technology are equivalent in their tolerance to Roundup agricultural herbicides. Products with Roundup Ready Technology contain in-plant tolerance to Roundup agricultural herbicides.

The Roundup Ready® Technology system's flexibility, broad-spectrum weed control and proven crop safety offer farmers weed control programs that allow them to use the system in the way that provides the greatest benefit. Farmers can select the program that best fits the way they farm. Options include the use of a residual herbicide with a Roundup® agricultural herbicide, tank-mixing other herbicides with Roundup agricultural herbicides where appropriate and a total postemergence program.

AGRONOMIC PRINCIPLES

Corn yield is very sensitive to early-season weed competition. Weed control systems must provide farmers the opportunity to control weeds before they become competitive. The Roundup Ready Technology system provides a mechanism to control weeds at planting and once they emerge. Farmers are provided excellent crop safety and full yield potential, with applications made from planting through 48" of corn height. Drop nozzles must be used between 30" and 48" of corn height. Failure to control weeds with the right rate, at the right time and with the right product, can lead to increased weed competition, weed escapes and the potential for decreased yields. Use other approved herbicide products with Roundup agricultural herbicides if appropriate for the weed spectrum.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
For use where residual herbicides are typically used for early-season weed control: **Residual Herbicide Plus Roundup WeatherMAX®**	Use the proper Roundup Ready RATE™ of Bullet®, Degree®, Degree Xtra®, Harness®, Harness Xtra, Harness Xtra 5.6L, Micro-Tech™, or Lariat® (no post) as defined in the table below and the individual product labels, either pre or postemergence to the crop.** Follow with Roundup WeatherMAX at 16 to 22 oz/A post sequentially after preemergence application or tank-mixed in-crop with the residual. Applications should be made before weeds exceed 4" in height. **Roundup Ready RATEs***** Harness 1.5 Pints Degree 3.0 Pints Harness Xtra 1.2 Quarts Harness Xtra 5.6L 1.5 Quarts Degree Xtra 2.0 Quarts Micro-Tech 2.0 Quarts Lariat 2.0 Quarts Bullet 2.0 Quarts	Use full labeled rate of residual when application is 14 days or more prior to planting or when tough grasses are present, e.g., barnyardgrass, shattercane, seedling johnsongrass, sandbur. Use a minimum of 2.5 pt/A of Harness on woolly cupgrass and wild proso millet. Products containing atrazine will provide improved control of cocklebur, giant ragweed, *Palmer Amaranth* and morningglory. Tank-mix products such as 2,4-D, dicamba or Status® herbicide with Roundup WeatherMAX for control of glyphosate-resistant marestail (horseweed), *Palmer Amaranth* and other difficult-to-control weeds. Use 22 to 32 oz/A of Roundup WeatherMAX* when morningglory or perennial weeds are present or when broadleaf weeds are 4" in height or taller.
For use where total postemergence programs are effective and sustainable: **Roundup WeatherMAX Sequential**	Apply Roundup WeatherMAX at 16 to 22 oz/A before weeds exceed 4" in height and follow with a second application at 16 to 22 oz/A for an additional flush of weeds before they exceed 4" in height.	Use 22 to 32 oz/A of Roundup WeatherMAX when morningglory or perennial weeds are present. Tank-mix products such as 2,4-D, dicamba or Status herbicide with Roundup WeatherMAX for control of glyphosate-resistant marestail (horseweed), *Palmer Amaranth* and other difficult-to-control weeds.
Maximum Use Rates For Roundup WeatherMAX	**Products with Roundup Ready 2 Technology In-crop:** • 32 oz/A per single application • Total: 64 oz/A from emergence through 48" height of corn, drop nozzles must be used from 30" to 48" corn.	**Products with Roundup Ready 2 Technology Total Season:** The combined total of preplant, in-crop and preharvest applications of Roundup WeatherMAX can not exceed 5.3 qt/A. The combined total of in-crop and preharvest applications can not exceed 66 oz/A.

*If using another Roundup agricultural herbicide, you must refer to the label booklet or Roundup Ready Corn 2 Technology supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX®, application rates are the same as for Roundup WeatherMAX. If using another residual herbicide, follow the labeled use rate instructions applicable to Roundup Ready Corn 2. Follow all pesticide label requirements.

**Atrazine may also be used as a residual herbicide in the Roundup Ready Corn 2 System.

***You may apply up to the full residual herbicide labeled rate for corn.

WEED RESISTANCE MANAGEMENT FOR CORN WITH ROUNDUP READY TECHNOLOGY

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Roundup Ready Technology system.

- Start clean with a burndown herbicide or tillage. Early-season weed control is critical to yield.
- Apply pre-emergence residual herbicides such as Harness Xtra, Degree Xtra or other residual herbicides at the recommended rate.
- Or apply a pre-emergence residual herbicide at the recommended rate tank-mixed with Roundup WeatherMAX® at a minimum of 22 oz/A in-crop before weeds exceed 4" in height.
- Follow with a postemergence in-crop application of Roundup WeatherMAX at a minimum of 22 oz/A for additional weed flushes before they exceed 4" in height.
- Roundup WeatherMAX may be tank-mixed with other herbicides for postemergence weed control.
- Report repeated non-performance to Monsanto or your local retailer.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS IN PRODUCTS WITH ROUNDUP READY TECHNOLOGY

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	Start clean with a burndown program or tillage. -Tank-mix Roundup agricultural herbicides with 2,4-D, or dicamba, according to the label directions. In-crop, tank-mix 22 ounces per acre of Roundup WeatherMAX with Clarity® (8 to 16 fluid ounces per acre) or 2,4-D (0.5 to 1.0 lb active ingredient per acre) from corn emergence to the 5-leaf stage of corn growth (approximately 8" tall). Or tank-mix 22 ounces per acre of Roundup WeatherMAX with 5 ounces per acre of Status® herbicide when the corn is 4" to 36" tall (V2 to V10). Marestail should not exceed 6" in height at the time of in-crop application.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	Start clean with a burndown program or tillage. Use a residual herbicide such as Harness Xtra, Harness Xtra 5.6L, Degree Xtra or other residual herbicide either preemergence or in-crop for control of *Amaranthus* species. In-crop, tank-mix Roundup WeatherMAX with other herbicides such as 2,4-D, dicamba (Clarity or Banvel®) or Status herbicide to control emerged weeds. Applications of Status herbicide should be made when the corn is between 4" and 36" tall (V2 to V10). Follow all label directions. *Amaranthus* species should not exceed 3" in height at the time of in-crop application.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	Start clean with a burndown program or tillage. Use a residual herbicide such as Harness Xtra, Harness Xtra 5.6L, Degree Xtra or other residual herbicide either preemergence or in-crop for control of *Ambrosia* species. In-crop, tank-mix Roundup WeatherMAX with other herbicides such as 2,4-D, dicamba (Clarity or Banvel) or Status herbicide to control emerged weeds. Applications of Status herbicide should be made when the corn is between 4" and 36" tall (V2 to V10). Follow all label directions. *Ambrosia* species should not exceed 3" in height at the time of in-crop application.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown program or tillage. Use a residual herbicide such as Harness Xtra, Harness Xtra 5.6L, Degree Xtra or other residual herbicide containing atrazine preemergence to reduce the competition from seedling johnsongrass prior to the emergence of corn. In-crop, tank-mix Roundup WeatherMAX with a herbicide such as Accent®, Equip™ or Option® for control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.



Genuity™ Bollgard II® and Bollgard® Cotton Descriptions

GENUITY™ BOLLGARD II® COTTON

Genuity™ Bollgard II® cotton contains two distinct insecticidal proteins from *Bacillus thuringiensis (B.t.)* that increase the efficacy and spectrum of control and reduce the chance that resistance will develop to the *B.t.* insecticidal proteins, relative to Bollgard® cotton. Genuity™ Bollgard II® cotton normally provides excellent, season-long control of tobacco budworm, pink bollworm and cotton bollworm. Genuity™ Bollgard II® cotton provides good protection against fall armyworm, beet armyworm, cabbage and soybean loopers and other secondary leaf- or fruit-feeding caterpillar pests of cotton. Applications of insecticides to control these insects are substantially reduced with Genuity™ Bollgard II® cotton.

BOLLGARD® COTTON

Bollgard cotton contains a single insecticidal protein from *B.t.* that provides good control against three major lepidopteran insect pests of cotton. Specifically, Bollgard cotton provides excellent, season-long control of tobacco budworm and pink bollworm, and suppression of cotton bollworm. When the above-mentioned insect larvae feed on Bollgard cotton plants, the *B.t.* protein protects the plants from damage by reducing larval survival. Under high infestation, application of insecticides may be necessary to protect Bollgard cotton.

BOLLGARD PHASE OUT

The U.S. Environmental Protection Agency has mandated the following terms and conditions:*

- Bollgard® cotton may be sold through September 30, 2009. After that date, all sales of Bollgard cotton are prohibited.
- All Bollgard cotton seed must be planted by midnight of July 1, 2010 (the expiration date of the Bollgard cotton registration). After July 1, 2010, planting of Bollgard cotton seed is prohibited. Any Bollgard cotton seed not planted on or before July 1, 2010, must be returned to either the retailer or to Monsanto. No refunds are to be issued on Bollgard cotton seeds bought for planting in 2010 and returned by growers.
- An adequate amount of refuge seed must be purchased for planting an appropriate refuge for Bollgard cotton. Purchase of refuge seed with the Bollgard cotton seed is mandatory, and such seed must be purchased by growers in advance of their receipt of Bollgard cotton seed. Any seed purchased for use as a refuge is non-refundable, unless the proportional amount of Bollgard cotton seed that the refuge seed would have supported is returned at the same time.
- Any order for replacement or additional Bollgard cotton seed for the 2010 planting season, that does not conform to the requirements stated above must be filled with Genuity™ Bollgard II® cotton seed (or other products with current registrations).
- On-farm IRM assessments will be conducted during the planting season.
- In 2010, Bollgard cotton may only be planted in: Alabama, Arkansas, Florida (North of Florida Route 60), Georgia, Kentucky, Louisiana, Maryland, Missouri, Mississippi, North Carolina, South Carolina, Tennessee, Texas (excluding the ten prohibited Texas panhandle counties of: Dallam, Sherman, Hansford, Ochiltree, Lipscomb, Hartley, Moore, Hutchinson, Roberts, and Carson) and Virginia.

*It is a violation of federal law to sell or distribute an unregistered pesticide.

NOTE: Sale or commercial planting of Bollgard®cotton is prohibited in certain states, including: Arizona, California, Colorado, Kansas, New Mexico and Oklahoma.

Sale or planting of Bollgard is prohibited in the Texas counties of: Carson, Dallam, Hansford, Hartley, Hutchison, Lipscomb, Moore, Ochiltree, Roberts, and Sherman.

Sale or commercial planting of both Genuity™ Bollgard II® and Bollgard is prohibited in Hawaii, Puerto Rico, the U.S. Virgin Islands, and in Florida south of Route 60 (near Tampa).

The *B.t. delta endotoxin* protein expressed in this cotton targets certain cotton insect pests. Routine applications of insecticides to control certain insects are usually unnecessary when cotton containing the *B.t. delta endotoxin* protein is planted. However, if insecticide applications are necessary to control certain cotton insect pests, follow all label requirements.

Genuity™ Bollgard II® and Bollgard® Cotton

INSECT RESISTANCE MANAGEMENT (IRM)

Lepidopteran cotton pests have demonstrated the ability to develop resistance to many chemical insecticides. As a preemptive measure, Genuity™ Bollgard II® and Bollgard® cotton must be managed in ways that will retard insect resistance development. These practices are designed to ensure that some lepidopteran populations are not exposed to the *B.t.* proteins so they can maintain susceptibility in select populations. In order to achieve this, refuge cotton that does not contain *B.t.* proteins must be planted.

GENUITY™ BOLLGARD II - DUAL EFFECTIVE DOSE

Resistance management is critical to the long-term viability of our technology and the benefits realized by our farmer customers. 2010 is a transition year for Monsanto *B.t.* cotton products as we shift all U.S. cotton acres toward the two-gene insect control product, Genuity™ Bollgard II® cotton. The move to multiple-gene products, including Genuity™ Bollgard II®, offers dual effective modes of action against target insect pests, increasing the longevity of the technology.

INTEGRATED PEST MANAGEMENT (IPM)

Integrated Pest Management (IPM) is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This information is used to manage pests in a manner that is least harmful to people, property and the environment.

Prevention

Using the best agronomic management practices in conjunction with the appropriate cotton varieties will yield the greatest benefits.

Use varieties, seeding rates and planting technologies appropriate for each specific geographical area. As much as possible, manage the crop to avoid plant stress.

- Employ appropriate scouting techniques and treatment decisions to preserve beneficial insects that can provide additional insect pest control.
- Manage for appropriate maturity and harvest schedules, destroy stalks immediately after harvest to avoid regrowth and minimize selection for resistance in late-season infestations.
- Use soil management practices that encourage destruction of over-wintering pupae.

Monitor and Identify

Fields should be carefully monitored for all pests, including cotton bollworms, to determine the need for remedial insecticide treatments. For target pests, scouting techniques and supplemental treatment decisions should take into account the fact that larvae must hatch and feed before they can be affected by the *B.t.* protein(s) in either Genuity™ Bollgard II® or Bollgard cotton. Fields should be scouted regularly, following periods of heavy or sustained egg lay, especially during bloom, to determine if significant larval survival has occurred. Scouting should include a modified whole-plant inspection, including terminals, squares, blooms, bloom tags and small bolls. Larvae larger than 1/4 inch (3- to 4-days old) are generally recognized as survivors that may not be controlled by Genuity™ Bollgard II® or Bollgard cotton.

Read the IRM/Grower Guide prior to planting for information on planting and Insect Resistance Management. If you do not have a copy of this Guide, you may download it at www.monsanto.com, or call 1-800-768-6387 to request a copy by mail.

Control

Monsanto recommends the use of appropriate remedial insecticide treatments to ensure desired levels of control if any cotton insect pest reaches locally established thresholds in Genuity™ Bollgard II® or Bollgard cotton.

Although Genuity™ Bollgard II® and Bollgard cotton will sustain less damage from some of the most troublesome lepidopteran pests, they will not provide protection against non-lepidopteran species. These insects should be monitored and treated with insecticides when necessary, using recommended thresholds. Whenever possible, select insecticides that are least harmful to beneficial insects.

NOTE: In 2010, sale or commercial planting of Bollgard® cotton is prohibited in the following states: Arizona, California, Colorado, Kansas, New Mexico and Oklahoma.

In 2010, sale or planting of Bollgard® is prohibited in the Texas counties of: Carson, Dallam, Hansford, Hartley, Hutchison, Lipscomb, Moore, Ochiltree, Roberts, and Sherman.

In 2010, sale or commercial planting of both Genuity™ Bollgard II® and Bollgard® is prohibited in Hawaii, Puerto Rico, and the U.S. Virgin Islands, or in Florida south of Route 60 (near Tampa).

Roundup Ready® Cotton, Genuity™ Bollgard II® with Roundup Ready® Cotton and Bollgard with Roundup Ready Cotton

ROUNDUP READY COTTON

Roundup Ready® cotton varieties contain in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to make in-crop applications of Roundup WeatherMAX® or Roundup PowerMAX® according to label requirements.

GENUITY™ BOLLGARD II WITH ROUNDUP READY COTTON AND BOLLGARD WITH ROUNDUP READY COTTON

Genuity™ Bollgard II® with Roundup Ready® cotton and Bollgard with Roundup Ready varieties offer farmers the benefits of both insect protection and glyphosate tolerance combined in one crop. These varieties exhibit the same insect protection qualities as Genuity™ Bollgard II® and Bollgard cotton and enable farmers to make in-crop applications of Roundup WeatherMAX or Roundup PowerMAX according to label requirements.

MARKET OPTIONS

Gin by-products of cotton containing Monsanto's biotech traits, including cottonseed for feed uses, are fully approved for export to Canada, Japan, Mexico and South Korea. Cottonseed containing Monsanto traits may not be exported for the purpose of planting without a license from Monsanto.

It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted.

RECOMMENDED MANAGEMENT PRACTICES

Managing Roundup Ready cotton, Bollgard with Roundup Ready cotton and Genuity™ Bollgard II® with Roundup Ready® cotton requires that a farmer follow the recommended management practices associated with cotton containing each individual trait. Farmers of Bollgard with Roundup Ready cotton and Genuity™ Bollgard II® with Roundup Ready® cotton varieties must follow the same guidelines for establishing required refuge options, practicing IRM and managing target and non-target pests as described for Bollgard and Genuity™ Bollgard II® cotton in the IRM/Grower Guide.

APPLICATION OF ROUNDUP WEATHERMAX® AND ROUNDUP POWERMAX®

Roundup Ready cotton is genetically improved to provide tolerance to glyphosate, the active ingredient in Roundup agricultural herbicides. Roundup Ready cotton can receive over-the-top applications of Roundup agricultural herbicides only through the four-leaf stage. With the introduction of Genuity™ Roundup Ready® Flex cotton, there is the potential for both Roundup Ready cotton and Genuity™ Roundup Ready® Flex cotton to be used on a farmer's farm. This creates concern for the crop safety of Roundup Ready cotton. Monsanto recommends that farmers:

- Maintain accurate records of which technologies have been planted and where they have been planted.
- Communicate the field plan with other members of their work force to ensure proper applications for each technology.
- Clearly mark fields to indicate which technology has been planted.



WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and these guidelines to minimize the risk of developing glyphosate-resistant weed populations in a Roundup Ready cotton system:

- Scout fields before and after each burndown and in-crop application.
- Start clean with a burndown herbicide program or tillage.
- Use the right herbicide product at the right rate and right time.
- Add soil residual herbicide(s) and cultural practices as part of a Roundup Ready weed control program.
- In-crop, apply Roundup WeatherMAX at a minimum of 22 oz/A when weeds are less than 6" in height.
- Tank-mix other approved herbicides with Roundup WeatherMAX if necessary for postemergence weed control.
- Clean equipment before moving from field to field to minimize the spread of weed seed (as well as nematodes, insects and other cotton pests).
- Should repeated non-performance occur, report to Monsanto or your local retailer.

WEED CONTROL RECOMMENDATIONS

Weed control in cotton is essential to help maximize both fiber yield and quality potential. Cotton is very sensitive to early-season weed competition, which can result in unacceptable stands and/or reduced yield potential. The Roundup Ready® cotton system provides farmers with the right tools to control weeds before they become competitive.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	Always start clean by planting into a weed-free field using either tillage or a burndown application. In no-till and reduced-till systems, apply a preplant burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A in a tank-mix with dicamba or 2,4-D. See the dicamba and 2,4-D product label for rates and time intervals required between application and cotton planting. State restrictions may apply.	Early-season weed competition can result in unacceptable stands and/or reduced yield potential. This tank-mix is recommended for control and management of glyphosate-resistant marestail (*Conyza sp.*) or other tough-to-control weeds. Burndown application should be made far enough in advance of planting to control existing weeds.
Residual Herbicides	Apply residual herbicide(s) as part of a Roundup Ready cotton weed control program. Use the recommended label rate and timing of the residual herbicide applied. Refer to individual product labels for list of residual herbicides that may be used.	The residual herbicide(s) may be applied as either a preemergence (including preplant incorporated), postemergence, and/or layby application as allowed on the label of the specific product being used.
Over-The-Top through Fourth Leaf	Apply Roundup WeatherMAX over the top from crop emergence through the fourth true-leaf (node) stage (until the fifth true leaf reaches the size of a quarter). Two applications can be made during this period at a maximum rate of 22 oz/A per application. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label for rate recommendations for specific annual weeds.	In-crop over-the-top applications must be at least 10 days apart and the cotton must have at least two nodes of incremental growth between applications. Care should be taken to record growth stage at first application. In situations where the potential for weed infestations is high (including perennial weeds), make the first application early enough to allow a second application before cotton exceeds the fourth true-leaf stage. Over-the-top applications after the fourth true-leaf stage can result in boll loss, delayed maturity, and/or yield loss.
Selective Equipment	After the fourth true-leaf stage through layby, Roundup WeatherMAX may be applied using precision post-directed or hooded sprayers which direct the spray to the base of the cotton plant. Two post-directed applications can be made during this period at a maximum rate of 22 oz/A per application.	Place nozzles in a low horizontal position to permit spray pattern to overlap in the row while contact of spray solution with cotton leaves should be avoided to the maximum extent possible. Excessive foliar contact can result in boll loss, delayed maturity, and/or yield loss. There must be two nodes of growth and at least 10 days between applications.
Preharvest Over-The-Top Applications	Before harvest and after cotton reaches 20% boll-crack, if needed, apply up to 44 oz/A of Roundup WeatherMAX. This treatment is effective in controlling late-season perennial weeds and can improve harvest efficiency.	Applications must be made at least 7 days prior to harvest. Roundup agricultural herbicides are not effective for preharvest cotton regrowth in Roundup Ready cotton. Do not apply Roundup agricultural herbicides preharvest to crops grown for seed under contract at an authorized cotton seed company.

Roundup Ready cotton has excellent vegetative tolerance to Roundup WeatherMAX allowing early-season over-the-top applications. Incomplete reproductive tolerance requires that applications after the 4-leaf (node) stage be properly post-directed.

ATTENTION: Use of Roundup agricultural herbicides in accordance with label directions is expected to result in normal growth of Roundup Ready cotton, however, various environmental conditions, agronomic practices, and other factors make it impossible to eliminate all risks associated with the product, even when applications are made in conformance with the label specifications. In some cases, these factors can result in boll loss, delayed maturity, and/or yield loss.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or Roundup Ready cotton supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX®, application rates are the same as for Roundup WeatherMAX.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	Start clean with a burndown herbicide program or tillage. -Tank-mix Roundup agricultural herbicides with dicamba or 2,4-D (consult label for plant back timing). If you have dense stands of marestail, use a preplant residual herbicide at the recommended rate and timing, such as diuron (Direx®) or flumioxazin (Valor®). Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. In-crop, if applying post-directed to glyphosate-resistant marestail, Roundup WeatherMAX can be tank-mixed with other herbicides, such as diuron or MSMA. Marestail should be less than 6" in height at the time of in-crop application.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl®) plus fluometuron or fomesafen (Reflex®) or flumioxazin (Valor) for control of *Amaranthus* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor or other labeled chloracetamide herbicide before *Amaranthus* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Amaranthus* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl) plus fluometuron or fomesafen (Reflex)for control of *Ambrosia* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor before *Ambrosia* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Ambrosia* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown herbicide or tillage. Preplant incorporate a residual herbicide such as pendimethalin or trifluralin for control or suppression of seedling johnsongrass. Apply Roundup WeatherMAX in a tank-mix with herbicides such as SelectMAX®, Assure® II or Poast Plus for the control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

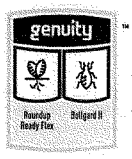
*Follow all pesticide label requirements.

Genuity™ Roundup Ready® Flex Cotton and Genuity™ Bollgard II® with Roundup Ready® Flex Cotton



GENUITY™ ROUNDUP READY® FLEX COTTON

Genuity™ Roundup Ready® Flex cotton varieties possess improved reproductive tolerance to Roundup® agricultural herbicides. This technology gives farmers the opportunity to make over-the-top broadcast applications of labeled Roundup agricultural herbicides from crop emergence up to seven (7) days prior to harvest.



GENUITY™ BOLLGARD II® WITH ROUNDUP READY® FLEX COTTON

Genuity™ Bollgard II® with Roundup Ready® Flex varieties offer farmers the benefits of both insect protection and glyphosate tolerance combined in one crop. These varieties exhibit the same insect protection qualities as Genuity™ Bollgard II® and are tolerant to over-the-top applications of Roundup WeatherMAX® and Roundup PowerMAX®.

MARKET OPTIONS

Genuity™ Roundup Ready® Flex cotton and Genuity™ Bollgard II® with Roundup Ready Flex cotton have regulatory clearance in the United States, but do not have import approval in all export markets. Processed fractions from these products, including linters, oil, meal, cottonseed and gin trash, must not be exported without all necessary approvals in the importing country. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted.

RECOMMENDED MANAGEMENT PRACTICES

Managing Genuity™ Roundup Ready® Flex cotton and Genuity™ Bollgard II® with Roundup Ready® Flex cotton requires a farmer to follow the recommended management practices associated with cotton containing each individual trait. Farmers of Genuity™ Bollgard II® with Roundup Ready® Flex cotton must follow the same guidelines for establishing required refuge options, practicing IRM and managing target and non-target pests as described for Genuity™ Bollgard II® cotton in the IRM/Grower Guide.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all label requirements and the guidelines below to minimize the risk of developing weed resistance in a Genuity™ Roundup Ready® Flex cotton system:

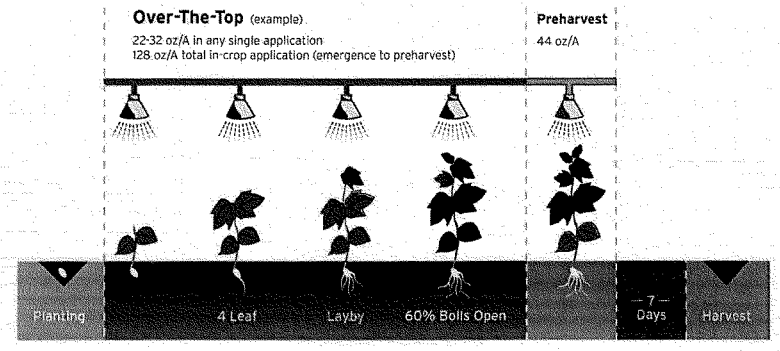
- Scout fields before and after each burndown and in-crop application.
- Start clean with a burndown herbicide program or tillage.
- Use the right herbicide product at the right rate and right time.
- Add soil residual herbicide(s) and cultural practices as part of a Genuity™ Roundup Ready® Flex cotton weed control program.
- In-crop, apply Roundup WeatherMAX at a minimum of 22 oz/A when weeds are 3" to 6" in height.
- Tank-mix other approved herbicides with Roundup WeatherMAX if necessary for postemergence weed control.
- Should repeated non-performance occur, report to Monsanto or your local retailer.
- Clean equipment before moving from field to field to minimize the spread of weed seed (as well as nematodes, insects and other cotton pests).

APPLICATION OF ROUNDUP WEATHERMAX® AND ROUNDUP POWERMAX®

- May be applied over-the-top and/or in-crop, from crop emergence up to 7 days prior to harvest.
- A maximum rate of 32 oz/A per application may be applied using ground application equipment while the maximum is 22 oz/A per application by air.
- There are no growth or timing restrictions for sequential applications.
- Four (4) quarts/A is the total in-crop volume allowed from emergence to 60% open bolls.
- A maximum total volume of 44 oz/A may be applied between layby and 60% open bolls.
- Post-directed equipment may be used to achieve more thorough spray coverage of weeds or if herbicides not labeled for over-the-top application will be tank-mixed with Roundup WeatherMAX or Roundup PowerMAX.

PREHARVEST APPLICATIONS

- Up to 44 oz/A may be applied after cotton reaches 60% open bolls and before harvest, if needed.
- Applications must be made at least 7 days prior to harvest.



CROP SAFETY OF OVER-THE-TOP GLYPHOSATE APPLICATIONS

Monsanto has determined that a combination of components in glyphosate formulations have the potential to cause leaf injury when applied during later stages of crop growth. Roundup WeatherMAX and Roundup PowerMAX are the only Roundup agricultural herbicides labeled and approved for new labeled uses over the top of Genuity™ Roundup Ready® Flex cotton.

Leaf injury may occur if the products are not used according to the product label, used at higher than recommended rates or if overlap of spray occurs in the field. **Farmers must confirm that any glyphosate formulation to be used on Genuity™ Roundup Ready® Flex cotton has been labeled for use on Genuity™ Roundup Ready® Flex cotton and should confirm that it has been tested to demonstrate crop safety.**

WEED CONTROL RECOMMENDATIONS

Weed control in cotton is essential to maximize both fiber yield and quality potential. Cotton is very sensitive to early-season weed competition, which can result in unacceptable stands and/or reduced yield potential. The Genuity™ Roundup Ready® Flex cotton system, with improved reproductive tolerance to Roundup® agricultural herbicides, provides farmers with the right tools to control weeds.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	Always start clean by planting into a weed-free field using either tillage or a burndown application. In no-till and reduced-till systems, apply a preplant burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A in a tank-mix with dicamba or 2,4-D. See the dicamba and 2,4-D product label for rates and time intervals required between application and cotton planting. State restrictions may apply.	Early-season weed competition can result in unacceptable stands and/or reduced yield potential. This tank-mix is recommended for control and management of glyphosate-resistant marestail (*Conyza sp.*) or other tough-to-control weeds. Burndown application should be made far enough in advance of planting to control existing weeds.
Residual Herbicides	Apply approved residual herbicide(s) as part of a Genuity™ Roundup Ready® Flex cotton weed control program. Use the recommended label rate and timing of the residual herbicide applied. Refer to individual product labels for list of residual herbicides that may be used.	The residual herbicide(s) may be applied as either a preemergence (including preplant incorporated), postemergence, and/or layby application as allowed on the label of the specific product being used.
In-Crop Weed Control	Target the first application of Roundup WeatherMAX on 1-2 leaf cotton when weeds are small. Apply a minimum of 22 oz/A of Roundup WeatherMAX in-crop. The need for sequential applications of Roundup WeatherMAX will depend upon the occurrence of subsequent weed flushes. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label booklet for rate recommendations for specific annual weeds.	Early-season weed competition can reduce yield potential in cotton. Select timing of application based on the most difficult to control weed species in your field. Post-direct or hooded sprayers can be used to achieve more thorough spray coverage on weeds.
Preharvest Over-The-Top Applications	Before harvest and after cotton reaches 60% open bolls, if needed, apply up to 44 oz/A of Roundup WeatherMAX. This treatment is effective in controlling late-season perennial weeds.	Applications must be made at least 7 days prior to harvest. Roundup agricultural herbicides are not effective for preharvest cotton regrowth in Genuity™ Roundup Ready® Flex cotton.

*Follow all pesticide label requirements.

**The maximum volume of Roundup WeatherMAX and Roundup PowerMAX® that may be used in a single season is 5.3 quarts per acre.





RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	Start clean with a burndown herbicide program or tillage. -Tank-mix Roundup agricultural herbicides with dicamba or 2,4-D (consult label for plant back timing). If you have dense stands of marestail, use a preplant residual herbicide at the recommended rate and timing, such as diuron (Direx®) or flumioxazin (Valor®). Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. In-crop, if applying post-directed to glyphosate-resistant marestail, Roundup WeatherMAX can be tank-mixed with other herbicides, such as diuron or MSMA. Marestail should not exceed 6" in height at the time of in-crop application.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl®) plus fluometuron or fomesafen (Reflex®) or flumioxazin (Valor) for control of *Amaranthus* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor or other labeled chloracetamide herbicide before *Amaranthus* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Amaranthus* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl) plus fluometuron or fomesafen (Reflex) for control of *Ambrosia* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor before *Ambrosia* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Ambrosia* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown herbicide or tillage. Preplant incorporate a residual herbicide such as pendimethalin or trifluralin for control or suppression of seedling johnsongrass. **Apply Roundup WeatherMAX in a tank-mix with herbicides such as SelectMAX®, Assure® II or Poast Plus for the control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.**

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.



GENUITY™ ROUNDUP READY 2 YIELD® AND ROUNDUP READY® SOYBEANS

Genuity™ Roundup Ready 2 Yield® and Roundup Ready® soybean varieties contain in-plant tolerance to Roundup® agricultural herbicides. This means you can spray Roundup agricultural herbicides in-crop from emergence through flowering.

Spray labeled Roundup agricultural herbicides over the top from emergence (cracking) through flowering (R2 stage soybeans) for unsurpassed weed control, proven crop safety and maximum yield potential. R2 stage soybeans end when a pod 5 millimeters (3/16") long at one of the four uppermost nodes appears on the main stem along with a fully developed leaf (R3 stage).

WEED CONTROL RECOMMENDATIONS

Starting clean with a weed-free field, and making timely post-emergence in-crop applications, is critical to obtaining excellent weed control and maximum yield potential. The Roundup Ready soybean system provides the flexibility to use the herbicide tools necessary to control weeds at planting and in-crop. Failure to control weeds with the right rate, at the right time and with the right product, can lead to increased weed competition and the potential for decreased yield.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	To start clean in no-till systems, apply a burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A before planting. See the label for appropriate rates by weed species. For control and management of glyphosate-resistant marestail (*Conyza sp.*) or other difficult-to-control weeds present at burndown, apply 22 oz/A of Roundup WeatherMAX in a tank-mix with 1 to 2 pt/A 2,4-D. Make applications 7 to 30 days before planting and before marestail reaches 6" in height.	Always start with a weed-free field. In no-till and reduced-till systems, apply a Roundup WeatherMAX® burndown application to control existing weeds before planting. Adding 2,4-D in the burndown can significantly reduce broadleaf weed pressure at post-emergence timing. Read the 2,4-D product label for time intervals required between application and soybean planting.
Residual Herbicide Plus Roundup WeatherMAX	Use the recommended label rate of a soil-applied residual herbicide applied preemergence to soybeans as defined in the individual product's labeling. The residual product may be tank-mixed with Roundup WeatherMAX at burndown. Refer to individual product labels for list of residual herbicides that may be used. Follow with 22 oz/A Roundup WeatherMAX in-crop when weeds are 2" to 8" tall. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label for rate recommendations for specific annual weeds. Crop rotation following Genuity™ Roundup Ready 2 Yield® and Roundup Ready soybeans is strongly encouraged. Use of a residual herbicide is encouraged especially if the cropping system is a continuous Roundup Ready system.	A residual program is encouraged when agronomic conditions favor the practice. Reducing Roundup WeatherMAX rate when tank-mixing with a residual or use of premixes utilizing a reduced rate of glyphosate (such as Extreme®) is not recommended. If the in-crop application is delayed and weeds are larger, apply a higher rate of Roundup WeatherMAX.
Roundup WeatherMAX	Apply a minimum of 22 oz/A of Roundup WeatherMAX** in-crop when weeds are 2" to 8" tall. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label for rate recommendations for specific annual weeds. Choose the rate to control the most difficult-to-control weed in your field. A sequential application of this product may be required to control new flushes of weeds in the Roundup Ready soybean crop. If a sequential application is necessary, apply 16 to 22 oz/A of Roundup WeatherMAX** when weeds are 3" to 6" tall.	In-crop application of Roundup WeatherMAX provides control of labeled weeds. For best results, apply 3 to 4 weeks after planting or when weeds are less than 8" tall. If initial application is delayed and weeds are larger, apply a higher labeled rate of Roundup WeatherMAX.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or Genuity™ Roundup Ready 2 Yield® soybean or Roundup Ready soybean supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GENUITY™ ROUNDUP READY 2 YIELD® AND ROUNDUP READY® SOYBEANS

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Glyphosate-Tolerant Volunteer Corn	Tank-mix Roundup WeatherMAX® with 6 to 12 oz/A of Select Max® and apply to 4" to 36" glyphosate-tolerant volunteer corn.	Choose your Roundup WeatherMAX rate based on the weed species and size listed in the "Annual Weeds Rate Table" of the Roundup WeatherMAX Label.
Maximum Use Rates for Roundup WeatherMAX	**In-Crop:** • 44 oz/A per single application • 44 oz/A during flowering • 64 oz/A emergence through flowering (R2 stage soybeans) **Preharvest:** • 22 oz/A application	**Total Season:** The combined total of preplant, in-crop and preharvest applications of Roundup WeatherMAX can not exceed 5.3 qt/A. The combined total of in-crop and preharvest applications can not exceed 64 oz/A.

*Follow all pesticide label requirements.

Herbicide products sold by Monsanto for use over the top of soybeans with Genuity™ Roundup Ready 2 Yield® Technology for the 2010 crop season are as follows:

- Roundup WeatherMAX
- Roundup PowerMAX

WEED CONTROL RECOMMENDATIONS

KEY WEEDS	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Weeds that Tend to Have Multiple Emergence Events	Where dense stands of weed species such as common lambsquarters, tall and common waterhemp, *Palmer Amaranth*, redroot pigweed, common ragweed, and giant ragweed are expected, the following agronomic practices are recommended: • Start clean with tillage or burndown in no-till and reduced till systems. include 2,4-D in the burndown. • Plant soybeans in narrow rows (<20"). • Use a pre-plant residual herbicide. • Use the right rate of Roundup WeatherMAX at the right time (proper weed size).	Weeds such as lambsquarters, waterhemp, pigweed, and giant ragweed tend to emerge throughout the season. Sequential Roundup WeatherMAX applications or the addition of a soil residual herbicide may be required for control of subsequent weed flushes.
Difficult-to-Control Weeds	Black nightshade, velvetleaf, waterhemp, morningglory, lambsquarters, Florida pusley, giant ragweed, Pennsylvania smartweed, groundcherry, hemp sesbania and spurred anoda are difficult-to-control weeds. Please refer to the Roundup agricultural herbicide label for specific rates and weed sizes for control of these weeds.	These weed species require special attention be paid to Roundup WeatherMAX rate and application timing (proper weed size) to obtain excellent weed control. A sequential application may be required if a new weed flush occurs, especially in soybeans planted in wide rows (>20").
Perennial Weeds	An in-crop application of 22 to 44 oz/A of Roundup WeatherMAX** will provide suppression and/or control of nutsedge and perennial weeds like Canada thistle, field bindweed, hemp dogbane, horsenettle, johnsongrass, milkweed, quackgrass, etc.	For additional information on perennial weeds, see the "Perennial Weeds Rate Table" in the label booklet for Roundup WeatherMAX. For best control, allow perennials to achieve at least 6" or more of growth before spraying.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or Roundup Ready Soybean or Genuity™ Roundup Ready 2 Yield® Soybean supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Roundup Ready Soybean System:

- Crop rotation is strongly encouraged.
- Scout fields before and after each burndown and in-crop application.



- Start clean with a burndown herbicide or tillage.
  - Tank-mix with 2,4-D to control glyphosate-resistant marestail or other tough-to-control broadleaf weeds.
- Use the recommended label rate of a soil-applied residual herbicide such as INTRRO®, Valor®, Valor XLT® or Gangster®.
- In-crop, apply Roundup WeatherMAX at a minimum of 22 oz/A before weeds exceed 8" in height.
- If an additional flush of weeds occurs, a sequential application of Roundup WeatherMAX at 22 oz/A may be needed before weeds exceed 6" in height.
- Refer to individual product labels for a list of recommended tank-mix partners.
- Clean equipment before moving from field to field to minimize the spread of weed seed.
- Report repeated non-performance to Monsanto or your local retailer.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	**Preplant:** Apply a tank-mixture of 22 oz/A Roundup WeatherMAX® with 1 pt/A 2,4-D before marestail exceeds 6" in height. See the 2,4-D product label for time intervals required between application and planting. **In-crop:** It is strongly encouraged that marestail should be controlled prior to planting using recommended preplant burndown treatments. In-crop, apply a tank-mixture of 22 oz/A Roundup WeatherMAX with 0.3 oz/A FirstRate®. This treatment should be used as a salvage treatment only for a marestail infestation that was not controlled preplant. Application should be made between full emergence of the first trifoliate leaf and 50% flowering stage of soybeans. At the time of treatment, marestail should not exceed 6" in height.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	**Preplant:** Apply a tank-mix of 22 oz/A Roundup WeatherMAX with a preemergence residual herbicide such as alachlor (INTRRO®), flumioxazin (Valor®) or another residual herbicide for preemergence control of *Amaranthus* species. 2,4-D may be added to the tank-mix to help control emerged *Amaranthus* species and other broadleaf weeds preplant only. Follow label instructions regarding application timing relative to soybean planting. **In-crop:** It is strongly encouraged that a preemergence residual product be used to control *Amaranthus* species prior to emergence. If there is emerged *Amaranthus* in-crop, apply a tank-mixture of 22 oz/A Roundup WeatherMAX with a postemergence product with activity on *Amaranthus* such as lactofen (Cobra®), fomesafen (Flexstar®) or cloransulam (FirstRate). Applications should be made on emerged *Amaranthus* that does not exceed 3" in height. Read and follow all product label instructions. It is likely that visual soybean injury will occur with these tank-mixtures.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	**Preplant:** Apply a tank-mix of 22 oz/A Roundup WeatherMAX with a preemergence residual herbicide such as cloransulam (FirstRate) or cloransulam + flumioxazin (Ganster®) or another residual herbicide for preemergence control of *Ambrosia* species. 2,4-D may be added to the tank-mix to help control emerged *Ambrosia* species and other broadleaf weeds preplant only. Follow label instructions regarding application timing relative to soybean planting. **In-crop:** It is strongly encouraged that a preemergence residual product be used to control *Ambrosia* species prior to emergence. If there is emerged *Ambrosia* in-crop, apply a tank-mixture of 22 oz/A Roundup WeatherMAX with a postemergence product with activity on *Ambrosia* such as lactofen (Cobra) or fomesafen (Flexstar). Applications should be made on emerged *Ambrosia* that does not exceed 3" in height. Read and follow all product label instructions. It is likely that visual soybean injury will occur with these tank-mixtures.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown herbicide or tillage. Preplant incorporate a residual herbicide such as pendimethalin or trifluralin for control or suppression of seedling johnsongrass. Apply Roundup WeatherMAX in a tank-mix with herbicides such as SelectMAX®, Assure® II or Poast Plus for the control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.


CANOLA
ALFALFA
SUGARBEET

GENUITY™ ROUNDUP READY® ALFALFA

ATTENTION: Pursuant to a Court Order issued on May 3, 2007, Genuity™ Roundup Ready® alfalfa seed **CAN NOT be commercially sold or planted** until further administrative regulatory actions are completed. For more information, and the latest updates on Genuity™ Roundup Ready® alfalfa, go to www.roundupreadyalfalfa.com.

Genuity™ Roundup Ready® alfalfa varieties have in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to apply labeled Roundup agricultural herbicides up to 5 days before cutting for unsurpassed weed control, excellent crop safety and preservation of forage quality potential.

Hay and Forage Management Practices

Genuity™ Roundup Ready® alfalfa must be managed for high quality hay/forage production, including timely cutting to promote high forage quality (i.e. before 10% bloom) and to prevent seed development. In geographies where conventional alfalfa seed production is intermingled with forage production and the agronomic conditions (climate and water/irrigation availability) are such that forage alfalfa is allowed to stand and flower late in the season, Genuity™ Roundup Ready® alfalfa must be harvested at or before 10% bloom to minimize potential pollen flow from hay to common or conventional alfalfa seed production. Farmers who are unwilling to or who can not make this commitment to stewardship should not continue to grow Genuity™ Roundup Ready® alfalfa.

Genuity™ Roundup Ready® alfalfa varieties have excellent tolerance to over-the-top applications of labeled Roundup agricultural herbicides. An in-crop weed control program using Roundup WeatherMAX® or Roundup PowerMAX® will provide excellent weed control in most situations. A residual herbicide labeled for use in alfalfa may also be applied postemergence in alfalfa. Contact a Monsanto Representative, local crop advisor or extension specialist to determine the best option for your situation.

Stand Takeout and Volunteer Management

Crop rotations can be divided into two main groups, alfalfa rotated to: 1) grass crops (e.g. corn and cereal crops); and 2) broadleaf crops. More herbicide alternatives exist for management of volunteer alfalfa in grass crops. The recommended steps for controlling volunteer Genuity™ Roundup Ready® alfalfa are:

- Diligent Stand Takeout
- Start Clean
- Plan for Success
- Timely Execution

DILIGENT STAND TAKEOUT

Use appropriate, commercially available herbicide treatments alone for reduced tillage systems or in combination with tillage to terminate the Genuity™ Roundup Ready® alfalfa stand. Refer to your regional technical bulletin for specific stand takeout recommendations. **NOTE:** Roundup® agricultural herbicides are **not** effective for terminating Genuity™ Roundup Ready® alfalfa stands.

START CLEAN

If necessary, utilize tillage and/or additional herbicide application(s) after stand takeout, and before planting of the subsequent rotational crop to manage any newly emerged or surviving alfalfa.

PLAN FOR SUCCESS

Rotate the crops with known and available mechanical or herbicidal methods for managing volunteer alfalfa, keeping in mind that Roundup agricultural herbicides will not terminate Genuity™ Roundup Ready® alfalfa stands.

- Rotations to certain broadleaf crops are not advisable if the farmer is not willing to implement recommended stand termination practices.
- In the event that no known mechanical or herbicidal methods are available to manage volunteer alfalfa in the desired rotational crop, it is suggested that a crop with established volunteer alfalfa management practices be introduced into the rotation.

TIMELY EXECUTION

Implement in-crop mechanical or herbicide treatments for managing alfalfa volunteers in a timely manner; that is, before the volunteers become too large to control or begin to compete with the rotational crop.

Planting Requirements

Genuity™ Roundup Ready® alfalfa is not permitted to be planted in any wildlife feed plots.

Stewardship

All Genuity™ Roundup Ready® alfalfa farmers shall sign the Monsanto Technology/Stewardship Agreement (MTSA) limited-use license application which provides the terms and conditions for the authorized use of the product. Due to special circumstances, alfalfa farmers in the Imperial Valley of California will also sign an Imperial Valley Use Agreement (IVUA) with specific stewardship commitments. The MTSA or IVUA must be completed before purchase or use of seed.

Both the MTSA or IVUA explicitly prohibit all forms of commercial seed harvest on the stand. Every alfalfa farmer producing seed of Genuity™ Roundup Ready® alfalfa must possess an additional, separate and distinct seed farmer contract to produce Genuity™ Roundup Ready® alfalfa seed. Genuity™ Roundup Ready® alfalfa seed may not be planted outside of the United States, or for the production of seed or sprouts.

Any product produced from a Genuity™ Roundup Ready® alfalfa crop or seed, including hay and hay products, must be labeled and may only be used, exported to, processed or sold in countries where regulatory approvals have been granted. It is a violation of national and international laws to move material containing biotech traits across boundaries into nations where import is not permitted.

Pursuant to a Court Order issued on May 3, 2007, Genuity™ Roundup Ready® alfalfa farmers must adhere to the requirements set out in the December 18, 2007 USDA Administrative Order **(http://www.aphis.usda.gov/brs/pdf/RRA_AB_final.pdf)** until the USDA completes its regulatory process.

These requirements include, but are not limited to:

- Pollinators shall not be added to Genuity™ Roundup Ready® alfalfa fields grown only for hay production.
- Farm equipment used in Genuity™ Roundup Ready® alfalfa production shall be properly cleaned after use.
- Genuity™ Roundup Ready® alfalfa shall be handled and clearly identified to minimize commingling after harvest.

For additional information visit the USDA website: **http://www.aphis.usda.gov/biotechnology/alfalfa_history.shtml**

For more information and the latest updates on Genuity™ Roundup Ready® alfalfa, go to **http://www.roundupreadyalfalfa.com**

To meet sales reporting requirements, the seed supplier is required to identify and list all Genuity™ Roundup Ready® alfalfa field locations. Therefore, all farmers MUST PROVIDE their seed supplier with the GPS coordinates of all their Genuity™ Roundup Ready® alfalfa fields.



WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Genuity™ Roundup Ready® alfalfa system:

- Scout fields before and after each herbicide application.
- Use the right herbicide product at the right rate and at the right time.
- To control flushes of weeds in established alfalfa, make applications of Roundup WeatherMAX® or Roundup PowerMAX® herbicide at 22 to 44 oz/A before weeds exceed 6" in height, up to 5 days before cutting.
- Use other approved herbicide products tank-mixed or in sequence with Roundup agricultural herbicide if appropriate for the weed spectrum present as part of a Genuity™ Roundup Ready® alfalfa weed control program.
- Report repeated non-performance to Monsanto or your local retailer.

WEED CONTROL RECOMMENDATIONS

In established stands, to preserve the quality potential of forage and hay, applications should be made after weeds have emerged but before alfalfa re-growth interferes with application spray coverage of the target weeds.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Established Stands	After the first harvest of a newly established stand, up to 44 oz/A of Roundup WeatherMAX®** herbicide per cutting may be applied up to 5 days before each subsequent cutting. The combined total per year for all in-crop applications in established stands must not exceed 132 oz/A (4.1 qt/A) of Roundup WeatherMAX.	Applications between cuttings may be applied as a single application or in multiple applications (e.g. 2 applications of 22 oz/A). Sequential applications should be at least 7 days apart.
Weeds Controlled	For specific application rates and instructions for control of various annual and perennial weeds, refer to the Roundup WeatherMAX®* herbicide label booklet. Some weeds with multiple germination times or suppressed (stunted) weeds may require a second application of Roundup WeatherMAX®* herbicide for complete control. For some perennial weeds, repeated applications may be required to eliminate crop competition throughout the growing season.	In addition to those weeds listed in the Roundup WeatherMAX® label booklets, this product will suppress or control the parasitic weed, dodder (*Cuscuta* spp.) in Genuity™ Roundup Ready® alfalfa. Repeat applications may be necessary for complete control. For tough-to-control weeds or weeds not controlled by Roundup® agricultural herbicides use labeled rates of other approved herbicides, alone or in tank-mixtures, with Roundup agricultural herbicides.
Maximum Use Rates	**In-Crop:** - 44 oz/A per single application. - Established Stand Total: 44 oz/A per cutting up to 5 days before harvest.	**Total Per Year:** The combined total per year for all in-crop applications in established stands must not exceed 132 oz/A (4.1 qt/A) of Roundup WeatherMAX.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or separately published Genuity™ Roundup Ready® alfalfa supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GENUITY™ ROUNDUP READY® SPRING CANOLA

Genuity™ Roundup Ready® spring canola hybrids contain in-plant tolerance to Roundup agricultural herbicides, enabling farmers to apply Roundup® agricultural herbicides over the top of Genuity™ Roundup Ready® spring canola anytime from emergence through the 6-leaf stage of development.

The introduction of the Roundup Ready® trait into leading spring canola hybrids and varieties gives farmers the opportunity for unsurpassed weed control, proven crop safety and maximum profit potential. With Genuity™ Roundup Ready® spring canola, farmers have the weed management tool necessary to improve spring canola profitability, while providing a viable rotational crop to help break pest and disease cycles in cereal-growing areas.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Genuity™ Roundup Ready® spring canola system:

- Scout fields before and after each burndown and in-crop application.
- Start clean with a burndown herbicide or tillage.
- In-crop, apply Roundup WeatherMAX® herbicide before weeds exceed 3" in height.
- A sequential application of Roundup WeatherMAX herbicide may be needed.
- Clean equipment before moving from field to field to minimize the spread of weed seed.
- Report repeated non-performance to Monsanto or your local retailer.

WEED CONTROL RECOMMENDATIONS (SPRING-SEEDED)

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Two-Pass Program– For Annual and Perennial Weed Control	For broad-spectrum control of annual and perennial weeds, use an initial application of 11 oz/A of Roundup WeatherMAX**, in 5 to 10 gal/A water volume. No surfactant is required. Make a second application of 11 oz/A of Roundup WeatherMAX** no less than 10 days after initial application up to the 6-leaf stage (prebolting). Do not exceed 11 oz/A per application.	Spray when canola is at the 0- to 6-leaf stage of growth. To maximize yield potential, spray Genuity™ Roundup Ready® spring canola at the 1- to 3-leaf stage to eliminate competing weeds. Short-term yellowing may occur with later applications, with little effect on crop growth, maturity, or yield. Wait a minimum of 10 days between applications. Two applications of Roundup WeatherMAX will: • Control late flushes of annual weeds such as foxtail, pigweed, and wild mustard. • Provide season-long suppression of Canada thistle, quackgrass, and perennial sow thistle. • Provide better yields by eliminating competition from both annuals and hard-to-control perennials.
Single Application– For Annual Weed Control	For broad-spectrum control of annual and easy-to-control perennial weeds, make a single application of 16 oz/A of Roundup WeatherMAX.**	For best results, spray Genuity™ Roundup Ready® spring canola at the 2- to 3-leaf stage. Can be applied up to 6-leaf stage; yellowing may occur with later application with little effect on crop growth, maturity, or yield. No additional over-the-top applications can be made.
Maximum Use Rate For Roundup WeatherMAX	Two over-the-top applications: Do not exceed 11 oz/A per application. Single over-the-top applications: Do not exceed 16 oz/A. No additional application can be made.	

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or separately published Genuity™ Roundup Ready® canola supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GENUITY™ ROUNDUP READY™ WINTER CANOLA



Genuity™ Roundup Ready® winter canola varieties have been developed for seeding in the fall and harvesting the following spring/summer.

Genuity™ Roundup Ready® winter canola varieties contain in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to apply Roundup agricultural herbicides over the top of Genuity™ Roundup Ready® winter canola from crop emergence to the pre-bolting stage. The introduction of the Roundup Ready trait into winter canola varieties gives farmers the opportunity of unsurpassed weed control, crop safety and maximum yield potential. Genuity™ Roundup Ready® winter canola offers farmers an important option as a rotational crop in traditional monoculture winter wheat production areas. Introducing crop rotation is an important factor in reducing pest cycles, including weed and disease problems.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow the same guidelines as stated for spring canola.

WEED CONTROL RECOMMENDATIONS (WINTER-SEEDED)

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Sequential Applications	The two-pass program gives the greatest flexibility in controlling late emerging weeds. For broad-spectrum weed control, apply 11 to 22 oz/A of Roundup WeatherMAX** herbicide to 2-leaf or larger Genuity™ Roundup Ready® winter canola in the fall. Use 5 to 10 gallons/A water volume. Do not add surfactants. **Apply a second application of Roundup WeatherMAX** at 11 to 22 oz/A at a minimum interval of 60 days after the first application and before bolting in the spring.** Do not exceed 22 oz/A per application.	Spray when Genuity™ Roundup Ready® winter canola is at the 2-3 leaf stage of growth. Early applications can eliminate competing weeds and improve yield potential. Two applications of Roundup WeatherMAX will provide control of early emerging annual weeds and winter emerging weeds such as downy brome, cheat and jointed goatgrass.
Single Application	For broad-spectrum control of annual and easy-to-control perennial weeds, make a single application of 16 to 22 oz/A of Roundup WeatherMAX**, preferably in the fall.	For best results, spray Genuity™ Roundup Ready® winter canola at the 2-3 leaf stage and when weeds are small and actively growing. Applications must be made prior to bolting. Use the higher rate in the range when weed densities are high, when weeds have over wintered or when weeds become large and well established.
Maximum Use Rate for Roundup WeatherMAX	Any single over-the-top application of Roundup WeatherMAX** should not exceed 22 oz/A. No more than two over-the-top applications may be made from crop emergence to canopy closure prior to bolting in the spring.	Applications of greater than 16 fluid ounces/A prior to the 6-leaf stage may result in temporary yellowing and/or growth reduction.

*Follow all pesticide label requirements.

**If using another Roundup brand herbicide, you must refer to the label booklet or Genuity™ Roundup Ready® winter canola supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GRAZING

It is recommended that Genuity™ Roundup Ready® winter canola not be grazed. While Genuity™ Roundup Ready® winter canola may provide farmers additional opportunity as a forage for grazing livestock, at the present time insufficient information exists to allow safe and proper grazing recommendations. Preliminary data suggest that excessive grazing can significantly reduce yield, and that careful nitrate management is critical in managing Genuity™ Roundup Ready® winter canola as a forage to limit the risk of livestock nitrate poisoning. State universities are assessing the potential and the instructions for grazing Genuity™ Roundup Ready® winter canola and they will provide grazing management guidelines when their research is completed.

GENUITY™ ROUNDUP READY® SUGARBEETS

Genuity™ Roundup Ready® sugarbeet varieties have in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to apply labeled Roundup agricultural herbicides from planting through 30 days prior to harvest for unsurpassed weed control, excellent crop safety and preservation of yield potential.

MANAGEMENT PRACTICES

Sugarbeets are extremely sensitive to weed competition for light, nutrients and soil moisture. Research on sugarbeet weed control suggests that sugarbeets need to be kept weed-free for the first eight weeks of growth to protect yield potential. Therefore, weeds must be controlled when they are small and before they compete with Genuity™ Roundup Ready® sugarbeets (exceed crop height), that is from less than 2" up to 4" in height, to preserve sugarbeet yield potential. *More than one in-crop herbicide application will be required* to control weed infestations to protect yield potential as Roundup agricultural herbicides have no soil residual activity. Bolting sugarbeets must be rogued or topped in Genuity™ Roundup Ready® sugarbeet fields.

Genuity® Roundup Ready® sugarbeet varieties have excellent tolerance to over-the-top applications of labeled Roundup agricultural herbicides. A postemergence weed control program using Roundup WeatherMAX® or Roundup PowerMAX® will provide excellent weed control in most situations. A residual herbicide labeled for use in sugarbeets may also be applied preemergence, preplant or postemergence in Genuity™ Roundup Ready® sugarbeets. Contact a Monsanto Representative, local crop advisor or extension specialist to determine the best option for your situation.

WEED RESISTANCE MANAGEMENT FOR GENUITY™ ROUNDUP READY® SUGARBEETS

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Genuity™ Roundup Ready® sugarbeet system:

- Start clean with tillage and follow-up with a burndown herbicide, such as Roundup WeatherMAX, if needed prior to planting.
- Early-season weed control is critical to protect sugarbeet yield potential. Apply the first in-crop application of Roundup WeatherMAX at a minimum of 22 oz/A while weeds are less than 2" in height.
- Follow with additional postemergence in-crop application of Roundup WeatherMAX at a minimum of 22 oz/A for additional weed flushes before weeds exceed 4" in height.
- Add spray grade ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup® agricultural herbicides to maximize product performance.
- Use mechanical weed control/cultivation and/or residual herbicides where appropriate in your Genuity™ Roundup Ready® sugarbeets.
- Use additional herbicide modes of action/residual herbicides and/or mechanical weed control in other Roundup Ready crops you rotate with Genuity™ Roundup Ready® sugarbeets.
- Report repeated non-performance of Roundup agricultural herbicides to Monsanto or your local retailer.

AGRONOMIC PRINCIPLES IN SUGARBEETS

Sugarbeets are very sensitive to early-season weed competition. It is important to select the appropriate herbicide product, application rate and timing to minimize weed competition to protect yields. The Genuity™ Roundup Ready® sugarbeet system provides a mechanism to control weeds at planting and once Genuity™ Roundup Ready® sugarbeets emerge. Failure to control weeds with the right rate, at the right time and with the right product, can lead to increased weed competition, weed escapes and the potential for decreased yields. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended as they may result in crop injury and reduced pest control or antagonism.

PLANTING REQUIREMENTS

Genuity™ Roundup Ready® sugarbeets are not permitted to be planted in any wildlife feed plots.

STEWARDSHIP

All Genuity™ Roundup Ready® sugarbeet farmers shall sign the Monsanto Technology/Stewardship Agreement (MTSA) limited-use license application which provides the terms and conditions for the authorized use of the product. The MTSA must be signed and approved prior to purchase or use of seed.

WEED CONTROL RECOMMENDATIONS

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	After preplant tillage or bedding operations have been completed, a preplant burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A may be applied to control weeds that have germinated after tillage and prior to planting. See the label for appropriate rates by weed species and weed size.	Always utilize tillage to start with a weed-free field.
Over-The-Top Applications up to eight-leaf Genuity® Roundup Ready® Sugarbeets	Up to two applications of Roundup agricultural herbicides may be made prior to the 8-leaf stage of Genuity® Roundup Ready® sugarbeets. The first application of 22 to 32 oz/A of Roundup WeatherMAX** should be made when weeds are less than 2" in height to protect yield potential. Make an additional application of 22 to 32 oz/A of Roundup WeatherMAX before weeds exceed 4" in height. Maximum in-crop Roundup WeatherMAX prior to 8-leaf stage must not exceed 56 oz/A.	Sugarbeets are sensitive to weed competition and can lose yield rapidly if weeds are not controlled early. More than one in-crop Roundup WeatherMAX application will be required to control weed infestations to protect yield potential as Roundup agricultural herbicides have no soil residual activity. Add ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup agricultural herbicides to maximize product performance. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended. Sequential applications should be at least 10 days apart.
Over-The-Top Applications to greater than eight-leaf Genuity® Roundup Ready® Sugarbeets	Up to two additional applications of 22 oz/A of Roundup WeatherMAX can be made after the eight-leaf stage up to 30 days prior to harvest. Maximum in-crop Roundup WeatherMAX from 8-leaf stage up until 30 days prior to harvest must not exceed 44 oz/A.	Add ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup agricultural herbicides to maximize product performance. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended. Sequential applications should be at least 10 days apart.
Maximum Use Rates	**In-Crop:** • Two applications of Roundup WeatherMAX prior to the 8-leaf stage of Genuity® Roundup Ready® sugarbeets - 32 oz/A per single application up to the 8-leaf stage. - Combined maximum of 56 oz/A in-crop prior to the 8-leaf stage • Two applications of Roundup WeatherMAX after the 8-leaf stage up to 30 days prior to harvest - 22 oz/A per single application after the 8-leaf stage. - Combined maximum of 44 oz/A in-crop after the 8-leaf stage until 30 days prior to harvest	**Total Per Year:** The combined total per year for all Roundup WeatherMAX applications including pre-plant must not exceed 5.3 qt/A. Total in-crop application must not exceed 3 qt/A. Add ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup agricultural herbicides to maximize product performance. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or separately published Genuity® Roundup Ready® sugarbeets supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

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- Saves the equivalent of 585 mature trees
- Reduces solid waste by 35,308 pounds
- Reduces waste water by 213,390 gallons
- Reduces greenhouse gas emissions by 199,989.75 pounds

Before opening a bag of seed, be sure to read, understand and accept the stewardship requirements, **including applicable refuge requirements for insect resistance management,** for the biotechnology traits expressed in the seed as set forth in the Monsanto Technology Agreement that you sign. By opening and using a bag of seed, you are reaffirming your obligation to comply with the most recent stewardship requirements.

Roundup Ready® Alfalfa seed is currently not for sale or distribution. The movement and use of Roundup Ready® Alfalfa forage is subject to a USDA administrative Order available at http://www.aphis.usda.gov/brs/pdf/RRA_A8_final.pdf.

This stewardship statement applies to all products listed herein except Genuity™ VT Double PRO™, Genuity™ VT Triple PRO™ and Genuity™ SmartStax™. See restrictions related to Genuity™ Double PRO™, Genuity™ VT Triple PRO™ and Genuity™ SmartStax™ below:

Monsanto Company is a member of Excellence Through Stewardship® (ETS). Monsanto products are commercialized in accordance with ETS Product Launch Stewardship Guidance, and in compliance with Monsanto's Policy for Commercialization of Biotechnology-Derived Plant Products in Commodity Crops. This product has been approved for import into key export markets with functioning regulatory systems. Any crop or material produced from this product can only be exported to, or used, processed or sold in countries where all necessary regulatory approvals have been granted. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Growers should talk to their grain handler or product purchaser to confirm their buying position for this product. Excellence Through Stewardship® is a registered trademark of Biotechnology Industry Organization.

IMPORTANT: Grain Marketing and Seed Availability: Genuity™ VT Double PRO™ has received the necessary approvals in the United States, however, as of October 22, 2009, approvals have not been received in certain major corn export markets. **Genuity™ VT Double PRO™** will not be launched and seed will not be available until after import approvals are received in appropriate major corn export markets. ***B.t.* products, including Genuity™ VT Double PRO™** may not yet be registered in all states. Check with your Monsanto representative for the registration status in your state.

IMPORTANT: Grain Marketing and Seed Availability: Genuity™ VT Triple PRO™ has received the necessary approvals in the United States however, as of October 22, 2009, approval has not been received in all major corn export markets. Monsanto anticipates that all such approvals will be in place for the 2010 growing season. If all approvals are not in place, **Genuity™ VT Triple PRO™** seed will only be available as part of a commercial demonstration program that includes grain marketing stewardship requirements. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Consult with your seed representative for current regulatory and stewardship information status.

IMPORTANT: Grain Marketing and Seed Availability: Genuity™ SmartStax™ has received the necessary approvals in the United States, however, as of October 22, 2009, approvals have not been received in certain major corn export markets. **Genuity™ SmartStax™** will not be launched and seed will not be available until after import approvals are received in appropriate major corn export markets. ***B.t.* products, including Genuity™ SmartStax™** may not yet be registered in all states. Check with your Monsanto representative for the registration status in your state.

Cottonseed containing Monsanto traits may not be exported for the purpose of planting without a license from Monsanto.

Individual results may vary, and performance may vary from location to location and from year to year. This result may not be an indicator of results you may obtain as local growing, soil and weather conditions may vary. Growers should evaluate data from multiple locations and years whenever possible.

Growers may utilize the natural refuge option for varieties containing the Bollgard II® trait in the following states: AL, AR, FL, GA, KS, KY, LA, MD, MS, MO, NC, OK, SC, TN, VA, and most of Texas (excluding the Texas counties of Brewster, Crane, Crockett, Culberson, El Paso, Hudspeth, Jeff Davis, Loving, Pecos, Presidio, Reeves, Terrell, Val Verde, Ward and Winkler). The natural refuge option does not apply to **Bollgard II** cotton grown in areas where pink bollworm is a pest, including CA, AZ, NM, and the above listed Texas counties. It also remains the case that **Bollgard®** and **Bollgard II** cotton cannot be planted south of Highway 60 in Florida, and that **Bollgard** cotton cannot be planted in certain other counties in the Texas panhandle. Refer to the Technology Use Guide and IRM/Grower Guide for additional information regarding Bollgard II, Bollgard, natural refuge and EPA-mandated geographical restrictions on the planting of *B.t.* cotton.

ALWAYS READ AND FOLLOW PESTICIDE LABEL DIRECTIONS. Roundup Ready® crops contain genes that confer tolerance to glyphosate, the active ingredient in Roundup® brand agricultural herbicides. Roundup® brand agricultural herbicides will kill crops that are not tolerant to glyphosate. Degree® and Harness® are not registered in all states. Degree® and Harness® may be subject to use restrictions in some states. Bullet®, Degree Xtra®, Harness®, INTRRO®, Lariat®, and Micro-Tech® are restricted use pesticides and are not registered in all states. The distribution, sale, or use of an unregistered pesticide is a violation of federal and/or state law and is strictly prohibited. Check with your local Monsanto dealer or representative for the product registration status in your state.

Tank mixtures: The applicable labeling for each product must be in the possession of the user at the time of application. Follow applicable use instructions, including application rates, precautions and restrictions of each product used in the tank mixture. Monsanto has not tested all tank mix product formulations for compatibility or performance other than specifically listed by brand name. Always predetermine the compatibility of tank mixtures by mixing small proportional quantities in advance.

Bollgard®, Bollgard II®, Bullet®, Degree®, Degree Xtra®, Genuity™, Genuity and Design™, Genuity Icons, Harness®, INTRRO®, Lariat®, Micro-Tech™, Respect the Refuge and Cotton Design®, Roundup®, Roundup PowerMAX®, Roundup Ready®, Roundup Ready 2 Technology and Design™, Roundup Ready 2 Yield®, Roundup Ready RATE™, Roundup WeatherMAX®, Roundup WeatherMAX and Design®, SmartStax®, SmartStax and Design®, Start Clean, Stay Clean.™, Transorb and Design®, Vistive®, Vistive and Design®, VT Double PRO™, VT Triple PRO™, YieldGard®, YieldGard Corn Borer and Design®, YieldGard Plus and Design®, YieldGard Rootworm and Design®, YieldGard VT®, YieldGard VT and Design®, YieldGard VT Rootworm/RR2®, YieldGard VT Triple®, and Monsanto and Vine Design® are trademarks of Monsanto Technology LLC. Ignite® and LibertyLink® and the Water Droplet Design® are registered trademarks of Bayer. Herculex is a trademark of Dow AgroSciences LLC. Select Max® and Valor® are registered trademarks of Valent U.S.A. Corporation. Respect the Refuge® and Respect the Refuge and Corn Design® are registered trademarks of National Corn Growers Association. All other trademarks are the property of their respective owners. ©2009 Monsanto Company. (19282Apgd) SA-9Y-09-3881

Appendix B

National and Tier III Production Data and State Maps with County-Level Detail for the Eleven Tier III States with Seed Production Greater Than 100,000 lbs

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
ARIZONA	COCONINO							0	4	141		
ARIZONA	GILA							0	1	0		
ARIZONA	GREENLEE			0	0	0		1,126	19	6,767		
ARIZONA	LAPAZ	No	Yes, With Limits and GPS Reporting					60,290	52	451,583		
ARIZONA	MOHAVE							10,374	15	58,068		
ARIZONA	PIMA							1,888	23	19,303		
ARIZONA	SANTA CRUZ							0	2	0		
			Subtotals	0	0	0	0	73,678	116	535,862	12%	
ARIZONA	APACHE			0	2	0		0	146	4,372		
ARIZONA	COCHISE			0	1	0		19,621	65	142,696		
ARIZONA	GRAHAM			304	6	112,960		1,973	61	0		
ARIZONA	MARICOPA	Yes	No new RRA forage production	776	17	182,099		75,394	175	612,404		
ARIZONA	NAVAJO			0	2	0		2,694	48	7,561		
ARIZONA	PINAL			0	6	859,873		54,495	175	420,575		
ARIZONA	YAVAPAI			0	3	30,000		0	28	2,981		
ARIZONA	YUMA			1,723	16	708,212		25,789	129	228,082		
Subtotal			Subtotals	2,803	53	1,893,144	0	179,966	827	1,418,671		88%
			State Total	2,803	53	1,893,144	0	253,644	943	1,954,533		
CALIFORNIA	ALAMEDA	No	Yes, With Limits and GPS Reporting					0	4	2,770		
CALIFORNIA	ALPINE							0	1	0		
CALIFORNIA	AMADOR							1,613	4	9,692		
CALIFORNIA	BUTTE			0	0	0		1,349	20	7,782		
CALIFORNIA	CALAVERAS							0	1	0		
CALIFORNIA	COLUSA							14,900	49	104,403		
CALIFORNIA	CONTRA COSTA							3,696	15	22,423		
CALIFORNIA	GLENN							13,851	109	90,271		
CALIFORNIA	INYO							3,273	12	16,177		
CALIFORNIA	LAKE							58	8	347		
CALIFORNIA	LOS ANGELES			0	0	0		7,693	30	59,240		
CALIFORNIA	MARIN							0	0	0		
CALIFORNIA	MARIPOSA							0	0	0		

Appendix B

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds	Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
CALIFORNIA	MENDOCINO			0	0	0	1,218	7	5,325		
CALIFORNIA	MERCED			0	0	0	82,731	304	622,298		
CALIFORNIA	MONO						7,525	17	40,666		
CALIFORNIA	MONTEREY						428	12	2,633		
CALIFORNIA	NAPA						125	6	436		
CALIFORNIA	NEVADA						0	3	0		
CALIFORNIA	ORANGE						0	1	0		
CALIFORNIA	PLACER						170	4	0		
CALIFORNIA	PLUMAS						5,118	10	16,888		
CALIFORNIA	SAN BENITO						489	4	3,161		
CALIFORNIA	SAN BERNARDINO			0	0	0	9,345	43	66,349		
CALIFORNIA	SAN DIEGO						183	10	660		
CALIFORNIA	SAN JOAQUIN			0	0	0	56,969	225	394,624		
CALIFORNIA	SAN LUIS OBISPO						0	20	25,519		
CALIFORNIA	SAN MATEO						0	1	0		
CALIFORNIA	SANTA BARBARA						841	21	6,123		
CALIFORNIA	SANTA CLARA						1,213	8	7,268		
CALIFORNIA	SHASTA						4,894	54	21,418		
CALIFORNIA	SIERRA						1,064	11	3,594		
CALIFORNIA	SISKIYOU			0	0	0	59,216	194	267,718		
CALIFORNIA	SOLANO						28,129	69	197,659		
CALIFORNIA	SONOMA			0	0	0	925	11	4,119		
CALIFORNIA	STANISLAUS			0	0	0	28,836	259	220,581		
CALIFORNIA	SUTTER			0	0	0	6,388	39	40,765		
CALIFORNIA	TEHAMA						5,289	44	31,465		
CALIFORNIA	TRINITY						0	6	0		
CALIFORNIA	TULARE			0	0	0	76,413	306	624,055		
CALIFORNIA	TUOLUMNE						0	0	0		
CALIFORNIA	VENTURA						1,001	7	6,682		
CALIFORNIA	YUBA						850	9	4,267		
			Subtotals	0	0	0	425,793	1,958	2,927,378	55%	
CALIFORNIA	FRESNO	Yes	No new RRA forage production	3,287	20	2,603,178	69,290	250	528,024		

Counties Within Eleven States With Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
CALIFORNIA	HUMBOLDT			0	1	0		997	16	4,487		
CALIFORNIA	IMPERIAL			25,848	64	11,411,921		127,406	199	976,999		
CALIFORNIA	KERN			367	7	253,000		85,756	274	704,029		
CALIFORNIA	KINGS			5,779	5	4,295,319		63,840	243	485,411		
CALIFORNIA	LASSEN			377	4	190,000		19,752	119	85,017		
CALIFORNIA	MADERA			0	2	0		29,759	78	220,963		
CALIFORNIA	MODOC			65	5	41,000		45,890	159	217,036		
CALIFORNIA	RIVERSIDE			0	1	0		47,418	104	422,220		
CALIFORNIA	SACRAMENTO			0	2	0		9,960	65	75,678		
CALIFORNIA	YOLO			0	3	86,240		57,001	122	405,914		
			Subtotals	35,723	114	18,880,658	0	557,069	1,629	4,125,778		45%
			State Total	35,723	114	18,880,658	0	982,862	3,587	7,053,156		
IDAHO	ADAMS	No	Yes, With Limits and GPS Reporting					6,953	84	11,390		
IDAHO	BANNOCK							20,926	258	55,839		
IDAHO	BEAR LAKE							22,934	219	42,805		
IDAHO	BENEWAH							1,093	16	1,938		
IDAHO	BINGHAM			0	0	0		56,101	477	267,008		
IDAHO	BLAINE							22,083	101	78,802		
IDAHO	BOISE							1,471	25	0		
IDAHO	BONNER							4,298	90	7,340		
IDAHO	BONNEVILLE							41,382	348	160,554		
IDAHO	BOUNDARY			0	0	0		9,988	134	25,562		
IDAHO	BUTTE							31,843	110	123,505		
IDAHO	CAMAS							44,382	52	44,559		
IDAHO	CARIBOU							21,060	131	54,535		
IDAHO	CLARK							0	22	0		
IDAHO	CLEARWATER							1,544	16	2,634		
IDAHO	CUSTER							23,590	126	66,103		
IDAHO	FREMONT							17,469	184	55,889		
IDAHO	IDAHO							14,264	183	23,380		
IDAHO	JEFFERSON			0	0	0		80,999	432	389,645		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
IDAHO	KOOTENAI							5,362	100	11,974		
IDAHO	LATAH							4,156	90	8,391		
IDAHO	LEMHI							21,478	116	52,354		
IDAHO	LEWIS							4,469	57	9,744		
IDAHO	LINCOLN							23,248	145	104,300		
IDAHO	MADISON							15,114	183	58,374		
IDAHO	NEZ PERCE							0	91	10,414		
IDAHO	POWER							9,961	89	32,946		
IDAHO	SHOSHONE							0	3	0		
IDAHO	TETON							12,617	110	24,422		
IDAHO	VALLEY							1,304	22	3,585		
			Subtotals	0	0	0	0	520,089	4,014	1,727,992	46%	
IDAHO	ADA			0	8	609,015		20,972	461	88,529		
IDAHO	CANYON			7,018	31	5,940,842		40,654	867	230,714		
IDAHO	CASSIA			0	1	0		53,422	267	284,796		
IDAHO	ELMORE			0	1	0		38,569	162	167,200		
IDAHO	FRANKLIN			0	2	0		33,233	320	110,584		
IDAHO	GEM			233	7	129,588		10,747	241	43,580		
IDAHO	GOODING	Yes	No new RRA forage production	0	1	0		33,174	289	169,518		
IDAHO	JEROME			707	5	577,532		42,265	286	233,523		
IDAHO	MINIDOKA			0	1	0		29,381	269	168,412		
IDAHO	ONEIDA			0	6	430,150		28,802	178	97,341		
IDAHO	OWYHEE			1,179	11	877,054		48,409	307	281,034		
IDAHO	PAYETTE			496	9	267,467		15,850	290	75,673		
IDAHO	TWIN FALLS			258	5	151,500		68,924	596	395,914		
IDAHO	WASHINGTON			130	4	68,418		29,866	270	87,337		
			Subtotals	10,021	92	9,051,566	0	494,268	4,803	2,434,155		54%
			State Total	10,021	92	9,051,566		1,014,357	8,817	4,162,147		
MONTANA	CASCADE	No	Yes, With Limits and GPS Reporting					65,292	401	116,943		
MONTANA	DANIELS							19,602	95	26,311		
MONTANA	DEER LODGE							4,150	21	13,459		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds	Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
MONTANA	FERGUS			0	0	0	158,137	520	264,997		
MONTANA	GARFIELD						30,927	121	35,604		
MONTANA	GLACIER						28,397	151	45,795		
MONTANA	GOLDEN VALLEY						21,207	64	31,268		
MONTANA	GRANITE						8,720	50	26,982		
MONTANA	HILL						13,796	99	24,359		
MONTANA	JUDITH BASIN						79,911	181	142,981		
MONTANA	LAKE						33,618	379	89,981		
MONTANA	LEWIS AND CLARK						31,028	282	88,048		
MONTANA	LIBERTY						6,982	43	11,875		
MONTANA	MADISON						47,830	215	160,160		
MONTANA	MEAGHER						18,583	54	48,779		
MONTANA	MINERAL						1,332	25	2,323		
MONTANA	MISSOULA						9,158	157	23,051		
MONTANA	MUSSELSHELL			0	0	0	26,499	104	44,026		
MONTANA	PARK			0	0	0	38,637	205	117,514		
MONTANA	PONDERA						27,044	188	52,042		
MONTANA	POWELL						17,602	79	52,203		
MONTANA	RAVALLI						15,037	333	52,990		
MONTANA	ROOSEVELT						52,241	205	92,044		
MONTANA	SHERIDAN						19,749	125	34,294		
MONTANA	SILVER BOW						3,585	19	7,060		
MONTANA	SWEET GRASS						38,484	136	72,294		
MONTANA	TETON						42,172	240	108,722		
MONTANA	TOOLE						8,782	59	11,299		
MONTANA	VALLEY			0	0	0	51,908	257	112,848		
MONTANA	WHEATLAND						22,600	70	33,514		
MONTANA	WIBAUX						19,272	77	32,690		
			Subtotals	0	0	0	962,282	4,955	1,976,456	51%	
MONTANA	BEAVERHEAD	Yes	No new RRA forage production	0	1	0	42,828	145	141,961		
MONTANA	BIG HORN			619	7	341,502	70,177	293	181,466		
MONTANA	BLAINE			0	3	230,000	53,439	254	135,988		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
MONTANA	BROADWATER			0	1	0		20,608	115	80,074		
MONTANA	CARBON			0	12	1,253,336		34,963	309	87,750		
MONTANA	CARTER			560	3	76,000		68,447	185	103,119		
MONTANA	CHOUTEAU			0	1	0		25,519	149	42,578		
MONTANA	CUSTER			0	5	53,921		41,624	198	91,104		
MONTANA	DAWSON			0	1	0		29,735	206	54,018		
MONTANA	FALLON			105	3	22,341		73,050	165	83,380		
MONTANA	FLATHEAD			0	2	0		18,783	315	50,486		
MONTANA	GALLATIN			0	1	0		54,242	372	150,592		
MONTANA	JEFFERSON			0	2	0		13,747	83	41,164		
MONTANA	LINCOLN			0	1	0		3,341	70	5,873		
MONTANA	MCCONE			0	1	0		20,625	111	33,913		
MONTANA	PETROLEUM			0	1	0		26,304	53	49,588		
MONTANA	PHILLIPS			0	2	0		40,426	211	82,203		
MONTANA	POWDER RIVER			2,187	17	410,112		68,080	190	121,469		
MONTANA	PRAIRIE			0	2	0		14,352	88	28,379		
MONTANA	RICHLAND			0	1	0		44,729	227	92,452		
MONTANA	ROSEBUD			749	8	200,108		35,367	166	88,426		
MONTANA	SANDERS			0	1	0		13,685	129	28,181		
MONTANA	STILLWATER			0	1	0		43,459	222	59,995		
MONTANA	TREASURE			0	1	0		7,278	38	26,923		
MONTANA	YELLOWSTONE			0	2	0		41,666	462	98,907		
			Subtotals	4,220	80	2,587,320	0	906,474	4,756	1,959,989		49%
			State Total	4,220	80	2,587,320	0	1,868,756	9,711	3,936,445		
NEVADA	CARSON CITY	No	Yes, With Limits and GPS Reporting					0	2	0		
NEVADA	CLARK							1,742	28	0		
NEVADA	DOUGLAS							0	55	41,706		
NEVADA	ELKO							12,076	80	42,599		
NEVADA	ESMERALDA							12,114	13	58,110		
NEVADA	EUREKA							22,340	49	106,164		
NEVADA	LANDER							23,245	44	92,820		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
NEVADA	LYON							43,451	139	218,529		
NEVADA	MINERAL			0				0	4	0		
NEVADA	NYE							9,787	41	42,319		
NEVADA	STOREY							0	1	0		
NEVADA	WASHOE							4,134	101	14,842		
			Subtotals	0	0	0	0	128,889	557	617,089	49%	
NEVADA	CHURCHILL			162	5	129,000		25,955	294	122,839		
NEVADA	HUMBOLDT			4,206	6	3,024,793		51,041	101	215,768		
NEVADA	LINCOLN	Yes	No new RRA forage production	0	2	0		11,039	47	53,193		
NEVADA	PERSHING			1,960	4	1,067,308		30,625	74	145,593		
NEVADA	WHITE PINE			0	2	0		12,056	55	42,735		
			Subtotals	6,328	19	4,221,101	0	130,716	571	580,128		51%
			State Total	6328	19	4221101		259605	1128	1197217		
OKLAHOMA	ADAIR	No	Yes, With Limits and GPS Reporting					190	7	561		
OKLAHOMA	ATOKA							524	10	1,078		
OKLAHOMA	BEAVER							3,786	34	20,502		
OKLAHOMA	BECKHAM			-	-	-		5,527	76	16,930		
OKLAHOMA	BLAINE							6,525	89	20,137		
OKLAHOMA	BRYAN							4,071	31	11,658		
OKLAHOMA	CADDO							7,456	116	20,444		
OKLAHOMA	CANADIAN			-	-	-		14,541	165	46,215		
OKLAHOMA	CARTER							1,339	19	3,707		
OKLAHOMA	CHEROKEE							302	6	670		
OKLAHOMA	CHOCTAW							1,634	13	2,996		
OKLAHOMA	CIMARRON							5,390	16	26,933		
OKLAHOMA	CLEVELAND							3,482	46	10,993		
OKLAHOMA	COAL							260	9	656		
OKLAHOMA	COMANCHE							5,384	58	11,161		
OKLAHOMA	CRAIG							1,066	21	2,312		
OKLAHOMA	CUSTER							9,835	121	48,291		
OKLAHOMA	DELAWARE							352	18	1,001		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds	Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
OKLAHOMA	DEWEY						3,325	39	13,615		
OKLAHOMA	ELLIS						4,878	31	25,770		
OKLAHOMA	GARFIELD						7,838	108	24,312		
OKLAHOMA	GARVIN			-	-	-	17,535	133	68,099		
OKLAHOMA	GREER			-	-		4,437	39	14,481		
OKLAHOMA	HARMON						2,416	27	8,171		
OKLAHOMA	HASKELL						2,442	13	10,935		
OKLAHOMA	HUGHES						1,166	25	3,106		
OKLAHOMA	JACKSON			-	-	-	4,420	59	14,916		
OKLAHOMA	JEFFERSON						303	4	938		
OKLAHOMA	JOHNSTON						-	2	-		
OKLAHOMA	KINGFISHER			-	-	-	12,149	102	39,621		
OKLAHOMA	LATIMER						290	3	-		
OKLAHOMA	LEFLORE						1,973	22	3,165		
OKLAHOMA	LINCOLN			-	-	-	1,509	43	4,672		
OKLAHOMA	LOGAN			-	-	-	3,878	69	10,497		
OKLAHOMA	MAJOR			-	-	-	8,079	90	25,063		
OKLAHOMA	MARSHALL						-	4	160		
OKLAHOMA	MAYES						1,157	33	3,599		
OKLAHOMA	MCCLAIN						10,022	100	34,842		
OKLAHOMA	MCCURTAIN						2,094	40	5,364		
OKLAHOMA	MCINTOSH						519	16	1,293		
OKLAHOMA	MURRAY						2,254	18	7,483		
OKLAHOMA	NOBLE						5,315	92	13,656		
OKLAHOMA	NOWATA						996	25	3,499		
OKLAHOMA	OKFUSKEE						317	6	1,141		
OKLAHOMA	OKLAHOMA			-	-	-	5,565	75	17,875		
OKLAHOMA	OSAGE						2,802	55	8,210		
OKLAHOMA	OTTAWA						680	17	1,300		
OKLAHOMA	PAWNEE						1,667	38	6,427		
OKLAHOMA	PAYNE			-	-	-	2,560	47	9,524		
OKLAHOMA	PITTSBURG						681	12	1,642		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
OKLAHOMA	PONTOTOC							409	14	1,080		
OKLAHOMA	POTTAWATOMIE			-	-	-		2,510	61	5,679		
OKLAHOMA	PUSHMATAHA							497	6	1,186		
OKLAHOMA	ROGER MILLS							6,267	48	29,205		
OKLAHOMA	ROGERS							606	24	2,585		
OKLAHOMA	SEMINOLE							850	13	2,458		
OKLAHOMA	SEQUOYAH							968	18	2,183		
OKLAHOMA	TULSA							1,016	24	2,829		
OKLAHOMA	WASHINGTON							203	8	546		
OKLAHOMA	WOODS			-	-	-		13,060	106	40,906		
OKLAHOMA	WOODWARD							2,879	64	11,551		
			Subtotals	0	0	0		214,296	2,628	729,829	70%	
OKLAHOMA	ALFALFA			96	3	1,696		21,702	178	68,863		
OKLAHOMA	COTTON			-	2	-		813	14	1,665		
OKLAHOMA	CREEK			-	1	-		1,853	24	3,908		
OKLAHOMA	GRADY			275	5	4,350		22,971	220	70,671		
OKLAHOMA	GRANT			-	1	-		13,621	138	36,665		
OKLAHOMA	HARPER			-	2	-		3,421	38	11,823		
OKLAHOMA	KAY			-	2	-		6,991	119	19,145		
OKLAHOMA	KIOWA	Yes	No new RRA forage production	-	3	-		6,226	84	18,238		
OKLAHOMA	LOVE			-	1	-		328	11	901		
OKLAHOMA	MUSKOGEE			-	2	-		1,735	27	4,242		
OKLAHOMA	OKMULGEE			-	2	-		298	9	1,038		
OKLAHOMA	STEPHENS			-	1	-		2,222	26	6,829		
OKLAHOMA	TEXAS			-	1	-		6,611	32	31,588		
OKLAHOMA	TILLMAN			-	1	-		18,134	94	75,361		
OKLAHOMA	WAGONER			-	1	-		878	17	1,703		
OKLAHOMA	WASHITA			-	1	-		12,700	122	48,894		30%
			Subtotals	371	29	6,046		120,504	1,153	401,534		
			State Total	371	29	6046		334800	3781	1131363		
OREGON	BAKER	No	Yes, With Limits and GPS Reporting					22,057	215	80,919		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds	Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
OREGON	BENTON						390	9	2,620		
OREGON	CLACKAMAS						1,371	42	4,679		
OREGON	CLATSOP						185	5	513		
OREGON	COLUMBIA						345	12	0		
OREGON	COOS						268	8	616		
OREGON	CROOK						17,975	149	76,640		
OREGON	DESCHUTES						8,165	126	27,089		
OREGON	DOUGLAS						1,928	34	11,140		
OREGON	GRANT						8,796	80	17,985		
OREGON	HARNEY						45,514	178	150,512		
OREGON	JEFFERSON						15,175	146	65,594		
OREGON	JOSEPHINE						463	25	1,904		
OREGON	KLAMATH						61,859	335	271,713		
OREGON	LAKE						64,174	171	268,148		
OREGON	LANE			0	0	0	737	22	3,009		
OREGON	LINCOLN						130	3	0		
OREGON	LINN						829	23	3,122		
OREGON	MARION			0	0	0	1,740	69	6,219		
OREGON	MORROW						18,269	57	92,461		
OREGON	MULTNOMAH						238	12	640		
OREGON	POLK						342	19	1,402		
OREGON	SHERMAN						421	14	1,303		
OREGON	TILLAMOOK						326	3	0		
OREGON	UNION						26,633	314	80,843		
OREGON	WALLOWA						19,777	147	69,497		
OREGON	WHEELER						4,006	42	10,743		
OREGON	YAMHILL						1,781	51	5,747		
			Subtotals	0	0	0	323,894	2,311	1,255,058	65%	
OREGON	GILLIAM	Yes	No new RRA forage production	0	1	0	2,312	14	10,643		
OREGON	HOOD RIVER			0	1	0	236	14	452		
OREGON	JACKSON			0	1	0	4,127	104	14,850		
OREGON	MALHEUR			3,565	25	2,317,740	58,166	707	294,335		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
OREGON	UMATILLA			0	2	0		34,341	312	175,636		
OREGON	WASCO			0	1	0		4,451	70	18,402		
OREGON	WASHINGTON			0	1	0		1,285	37	5,550		
			Subtotals	3,565	32	2,317,740	0	104,918	1,258	519,868		35%
			Total	3,565	32	2,317,740		428,812	3,569	1,774,926		
SOUTH DAKOTA	AURORA	No	Yes, With Limits and GPS Reporting	0	0	0		17,065	159	52,198		
SOUTH DAKOTA	BEADLE			0	0	0		38,312	315	126,217		
SOUTH DAKOTA	BON HOMME							28,997	352	100,562		
SOUTH DAKOTA	BRULE			0	0	0		23,814	178	66,440		
SOUTH DAKOTA	BUFFALO							10,296	38	21,181		
SOUTH DAKOTA	BUTTE			0	0	0		46,953	299	119,239		
SOUTH DAKOTA	CHARLES MIX							42,202	358	122,162		
SOUTH DAKOTA	CLARK							23,158	208	70,286		
SOUTH DAKOTA	CLAY							17,946	140	66,019		
SOUTH DAKOTA	CODINGTON			0	0	0		22,632	244	72,022		
SOUTH DAKOTA	CUSTER							8,523	86	10,981		
SOUTH DAKOTA	DAVISON			0	0	0		19,504	209	60,524		
SOUTH DAKOTA	DAY			0	0	0		16,978	239	47,623		
SOUTH DAKOTA	DEUEL							15,882	224	57,396		
SOUTH DAKOTA	DOUGLAS							16,158	198	59,366		
SOUTH DAKOTA	EDMUNDS			0	0	0		27,401	164	66,818		
SOUTH DAKOTA	FALL RIVER			0	0	0		8,596	72	9,968		
SOUTH DAKOTA	FAULK							33,758	149	82,460		
SOUTH DAKOTA	GRANT							18,919	222	58,049		
SOUTH DAKOTA	HAAKON			0	0	0		44,691	146	35,926		
SOUTH DAKOTA	HAMLIN			0	0	0		10,296	153	36,251		
SOUTH DAKOTA	HAND							46,311	218	120,449		
SOUTH DAKOTA	HANSON							9,084	110	28,164		
SOUTH DAKOTA	HARDING							56,869	131	56,085		
SOUTH DAKOTA	HYDE							24,976	96	52,674		
SOUTH DAKOTA	JERAULD							20,034	110	61,931		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
SOUTH DAKOTA	JONES			0	0	0		25,627	82	38,332		
SOUTH DAKOTA	LAKE							10,956	200	36,862		
SOUTH DAKOTA	LAWRENCE							17,738	108	43,706		
SOUTH DAKOTA	LINCOLN							6,988	205	26,174		
SOUTH DAKOTA	MCCOOK							11,207	207	39,346		
SOUTH DAKOTA	MCPHERSON							46,056	180	117,492		
SOUTH DAKOTA	MINER							14,753	162	40,614		
SOUTH DAKOTA	MINNEHAHA			0	0	0		21,271	413	85,718		
SOUTH DAKOTA	MOODY							10,304	163	42,074		
SOUTH DAKOTA	PERKINS			0	0	0		101,477	260	138,351		
SOUTH DAKOTA	POTTER							12,155	68	26,927		
SOUTH DAKOTA	ROBERTS			0	0	0		21,618	268	68,944		
SOUTH DAKOTA	SANBORN			0	0	0		24,493	158	78,542		
SOUTH DAKOTA	SPINK			0	0	0		28,985	241	103,565		
SOUTH DAKOTA	STANLEY							10,430	55	12,373		
SOUTH DAKOTA	TODD			0	0	0		55,694	124	102,834		
SOUTH DAKOTA	UNION							7,753	143	33,192		
SOUTH DAKOTA	WALWORTH							20,749	105	46,700		
SOUTH DAKOTA	YANKTON							29,048	309	111,003		
SOUTH DAKOTA	ZIEBACH							34,754	101	33,260		
			Subtotals	0	0	0	0	1,161,411	8,370	2,887,000	66%	
SOUTH DAKOTA	BENNETT	Yes	No new RRA forage production	759	5	100,000		30,980	131	45,279		
SOUTH DAKOTA	BROOKINGS			0	2	0		19,123	299	65,750		
SOUTH DAKOTA	BROWN			0	1	0		32,865	315	100,125		
SOUTH DAKOTA	CAMPBELL			0	2	0		24,821	130	66,849		
SOUTH DAKOTA	CORSON			0	1	0		89,144	206	124,029		
SOUTH DAKOTA	DEWEY			2,113	9	50,000		65,514	186	92,402		
SOUTH DAKOTA	GREGORY			0	1	0		64,016	330	153,946		
SOUTH DAKOTA	HUGHES			0	1	0		9,816	97	17,901		
SOUTH DAKOTA	HUTCHINSON			0	1	0		23,966	300	90,463		
SOUTH DAKOTA	JACKSON			0	1	0		51,461	161	51,950		
SOUTH DAKOTA	KINGSBURY			0	1	0		22,344	218	71,982		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
SOUTH DAKOTA	LYMAN			0	1	0		21,977	111	39,503		
SOUTH DAKOTA	MARSHALL			324	4	23,782		23,530	187	64,281		
SOUTH DAKOTA	MEADE			0	5	30,500		150,760	489	181,724		
SOUTH DAKOTA	MELLETTE			0	2	0		43,478	146	59,893		
SOUTH DAKOTA	PENNINGTON			0	2	0		55,621	290	54,028		
SOUTH DAKOTA	SHANNON			0	1	0		9,094	39	10,968		
SOUTH DAKOTA	SULLY			0	2	0		6,121	39	14,082		
SOUTH DAKOTA	TRIPP			175	3	0		76,438	343	172,293		
SOUTH DAKOTA	TURNER			0	2	0		14,119	266	49,890		
			Subtotals	3,371	47	204,282	0	835,188	4,283	1,527,338		34%
			Total	3,371	47	204,282	0	1,996,599	12,653	4,414,338		
UTAH	BEAVER							19,908	120	102,373		
UTAH	CARBON			0	0	0		5,786	142	16,774		
UTAH	DAGGETT							3,761	20	9,850		
UTAH	DAVIS			0	0	0		3,715	155	18,078		
UTAH	EMERY			0	0	0		17,488	351	49,048		
UTAH	GARFIELD							9,738	156	26,741		
UTAH	GRAND							2,945	45	13,868		
UTAH	IRON							45,230	238	226,627		
UTAH	KANE							1,443	50	4,885		
UTAH	MORGAN	No	Yes, With Limits and GPS Reporting	0	0	0		9,406	165	24,368		
UTAH	PIUTE			0	0	0		8,870	73	24,732		
UTAH	RICH							9,270	78	22,164		
UTAH	SALT LAKE			0	0	0		3,324	153	12,577		
UTAH	SAN JUAN							5,300	64	9,792		
UTAH	SEVIER							25,878	394	109,322		
UTAH	SUMMIT			0	0	0		7,361	214	17,962		
UTAH	TOOELE							5,951	144	21,645		
UTAH	WASATCH			0	0	0		7,189	227	23,045		
UTAH	WASHINGTON			0	0	0		5,031	153	23,003		
UTAH	WAYNE							11,732	157	45,074		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
			Subtotals	0	0	0	0	209,326	3,099	801,928	40%	
UTAH	BOX ELDER			0	21	1,091,907		49,161	533	190,085		
UTAH	CACHE			580	6	311,706		50,741	636	193,480		
UTAH	DUCHESNE			60	3	30,000		33,357	423	110,596		
UTAH	JUAB			0	1	0		15,445	158	64,677		
UTAH	MILLARD	Yes	No new RRA forage production	1,118	16	426,700		72,244	421	343,717		
UTAH	SANPETE			0	1	0		35,994	475	139,572		
UTAH	UINTAH			0	2	0		36,019	497	125,099		
UTAH	UTAH			0	2	0		30,197	996	139,095		
UTAH	WEBER			0	2	0		16,086	542	63,969		
			Subtotals	1,758	54	1,860,313	0	339,244	4,681	1,370,290		60%
			Total	1,758	54	1,860,313		548,570	7,780	2,172,218		
WASHINGTON	ASOTIN	No	Yes, With Limits and GPS Reporting					673	10	0		
WASHINGTON	CHELAN							1,561	44	0		
WASHINGTON	CLALLAM							1,633	40	4,025		
WASHINGTON	CLARK							431	12	1,356		
WASHINGTON	COLUMBIA							1,284	29	3,462		
WASHINGTON	COWLITZ							0	1	0		
WASHINGTON	DOUGLAS			0	0	0		1,624	44	6,336		
WASHINGTON	GARFIELD							394	12	0		
WASHINGTON	GRAYS HARBOR							108	6	121		
WASHINGTON	ISLAND							1,612	20	3,186		
WASHINGTON	JEFFERSON							77	5	105		
WASHINGTON	KING							0	0	0		
WASHINGTON	KITSAP							0	2	0		
WASHINGTON	LEWIS							638	18	2,079		
WASHINGTON	PACIFIC							0	2	0		
WASHINGTON	PEND OREILLE							1,603	36	0		
WASHINGTON	PIERCE							105	7	399		
WASHINGTON	SAN JUAN							0	2	0		
WASHINGTON	SKAGIT							254	8	843		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

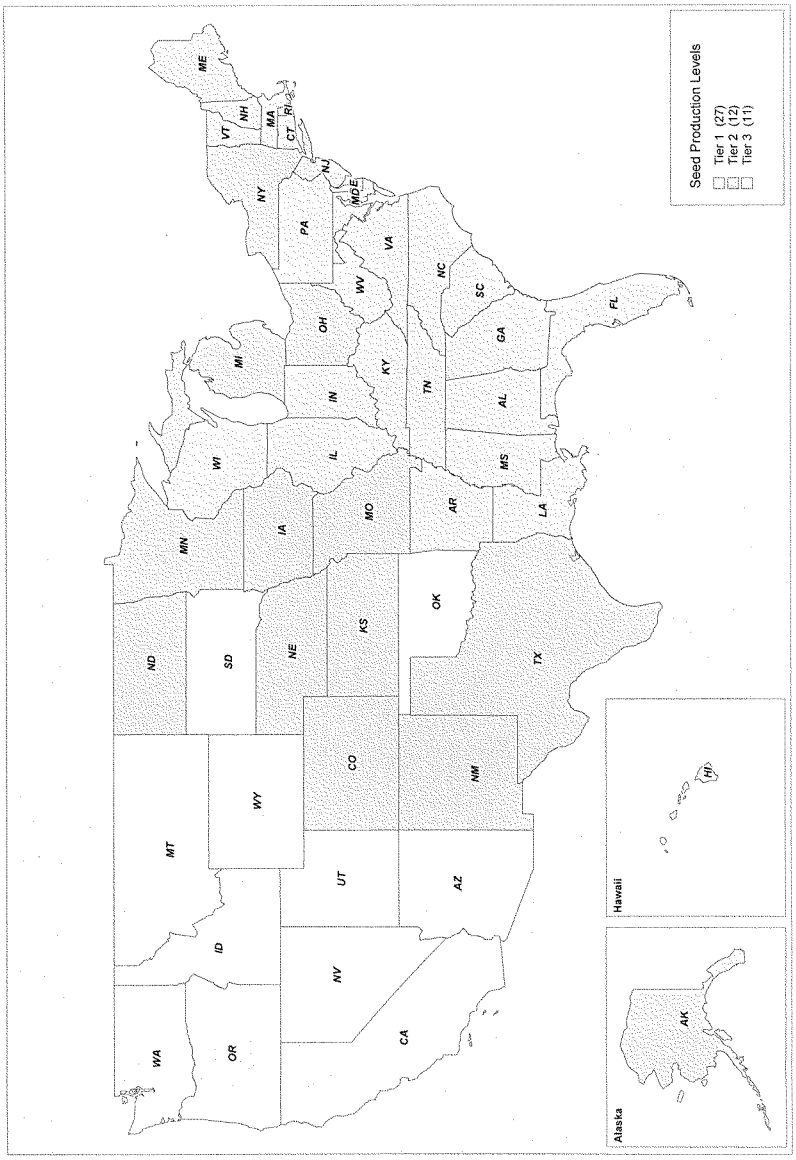
State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
WASHINGTON	SKAMANIA							0	2	0		
WASHINGTON	SNOHOMISH			0	0	0		632	14	2,432		
WASHINGTON	THURSTON							307	16	641		
WASHINGTON	WAHKIAKUM							0	1	0		
WASHINGTON	WHATCOM							791	16	2,208		
			Subtotals	0	0	0	0	13,727	347	27,193	8%	
WASHINGTON	ADAMS	Yes	No new RRA forage production	0	1	0		20,982	104	125,759		
WASHINGTON	BENTON			0	3	43,225		12,412	162	67,352		
WASHINGTON	FERRY			0	1	0		3,866	56	9,124		
WASHINGTON	FRANKLIN			311	5	238,526		77,441	272	573,937		
WASHINGTON	GRANT			4,249	25	2,308,614		117,488	549	752,332		
WASHINGTON	KITTITAS			0	1	0		8,721	165	35,824		
WASHINGTON	KLICKITAT			0	1	0		26,515	160	35,517		
WASHINGTON	LINCOLN			0	1	0		14,545	127	41,293		
WASHINGTON	OKANOGAN			129	7	25,731		23,253	399	73,994		
WASHINGTON	SPOKANE			0	3	19,200		36,386	656	77,020		
WASHINGTON	STEVENS			0	6	46,112		32,477	436	58,452		
WASHINGTON	WALLA WALLA			10,759	14	7,510,760		14,772	123	93,678		
WASHINGTON	WHITMAN			0	2	0		8,456	130	27,003		
WASHINGTON	YAKIMA			713	12	409,045		37,363	608	184,071		
			Subtotals	16,161	82	10,601,213	0	434,677	3,947	2,155,356		92%
			Totals	16,161	82	10,601,213	0	448,404	4,294	2,182,549		
WYOMING	ALBANY	No	Yes, With Limits and GPS Reporting					6,972	33	16,137		
WYOMING	CAMPBELL							45,631	177	61,739		
WYOMING	CARBON							14,065	61	21,953		
WYOMING	CONVERSE							28,914	135	62,321		
WYOMING	GOSHEN							58,944	369	179,960		
WYOMING	HOT SPRINGS							9,766	94	23,140		
WYOMING	JOHNSON							21,923	103	53,077		
WYOMING	LARAMIE							22,606	106	83,138		
WYOMING	LINCOLN							39,848	271	89,104		

Counties Within Eleven States with Seed Production greater than 100,000 lbs in 2007 (County List)

State	County	Seed Production Reported, 2007	Alfalfa For Forage Production	Seed - Acres Hvstd.	Seed - Operations	Seed - In Pounds		Alf. Hay - Acres	Alf. Hay - Operations	Alf. Hay - Tons	Hay % Operations Excluded	Hay % Operations Included
WYOMING	NATRONA							25,269	152	76,777		
WYOMING	NIOBRARA							12,974	60	30,041		
WYOMING	PLATTE							30,497	176	88,012		
WYOMING	SUBLETTE							5,485	29	10,312		
WYOMING	TETON							4,610	32	14,440		
WYOMING	UINTA							6,251	53	13,751		
WYOMING	WESTON							21,847	67	22,306		
			Subtotals	0	0	0	0	355,602	1,918	846,208	48%	
WYOMING	BIG HORN			0	18	2,816,147		35,845	332	126,064		
WYOMING	CROOK			0	3	0		77,829	232	104,988		
WYOMING	FREMONT			0	6	173,138		85,550	608	275,524		
WYOMING	PARK	Yes	No new RRA forage production	4,560	29	2,534,285		37,844	407	133,764		
WYOMING	SHERIDAN			0	1	0		45,376	268	113,207		
WYOMING	SWEETWATER			0	1	0		20,607	126	42,944		
WYOMING	WASHAKIE			0	4	244,826		15,631	116	53,739		
			Subtotals	4,560	62	5,768,396	0	318,682	2,089	850,230		52%
			Totals	4,560	62	5,768,396	0	674,284	4,007	1,696,438		
						Per State Average Exclusion/Inclusion:					46%	54%

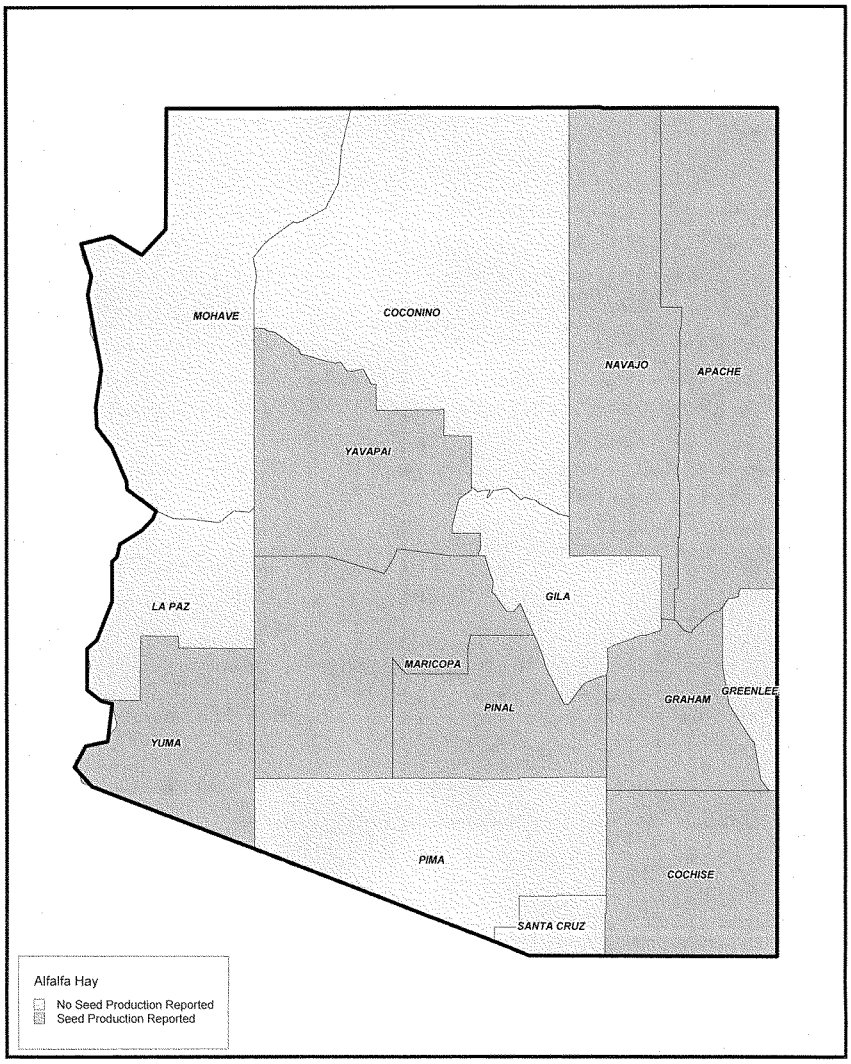
Appendix B

Seed Production Levels from 2007 Ag Census Data



Arizonia - Alfalfa Hay Counties With and Without Seed Production

Appendix B



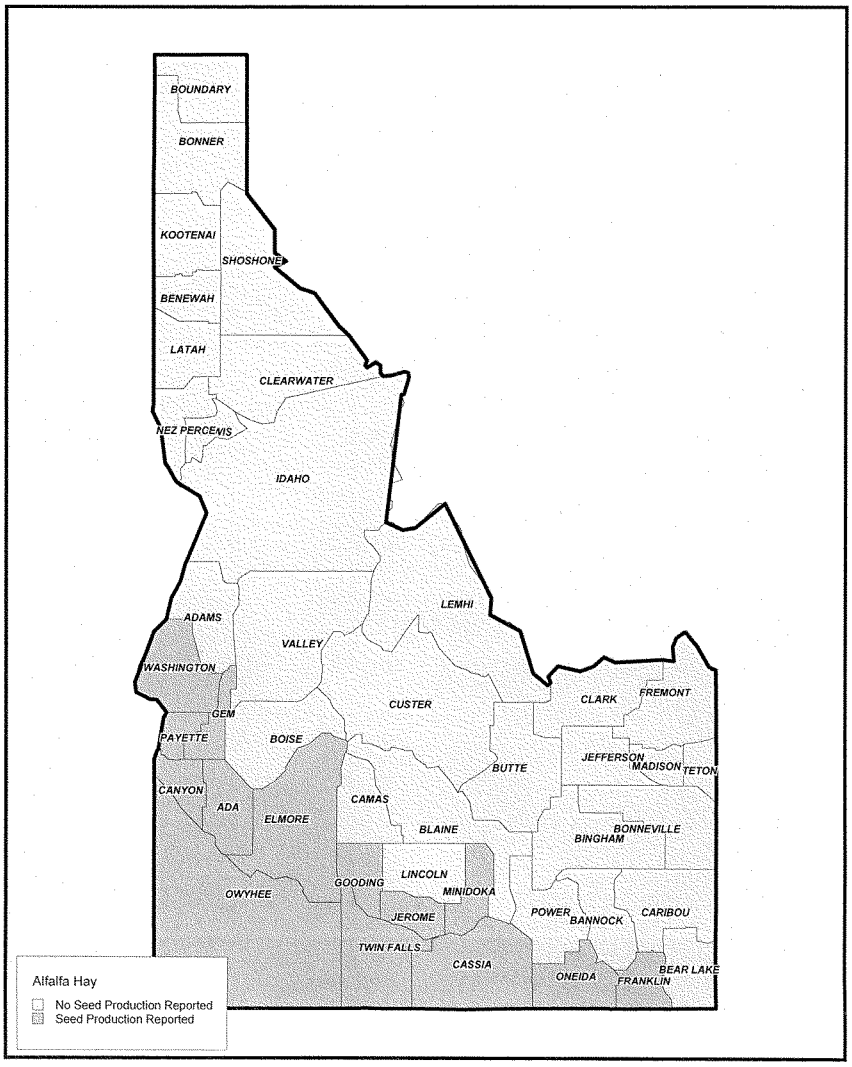
California - Alfalfa Hay Counties With and Without Seed Production

Appendix B



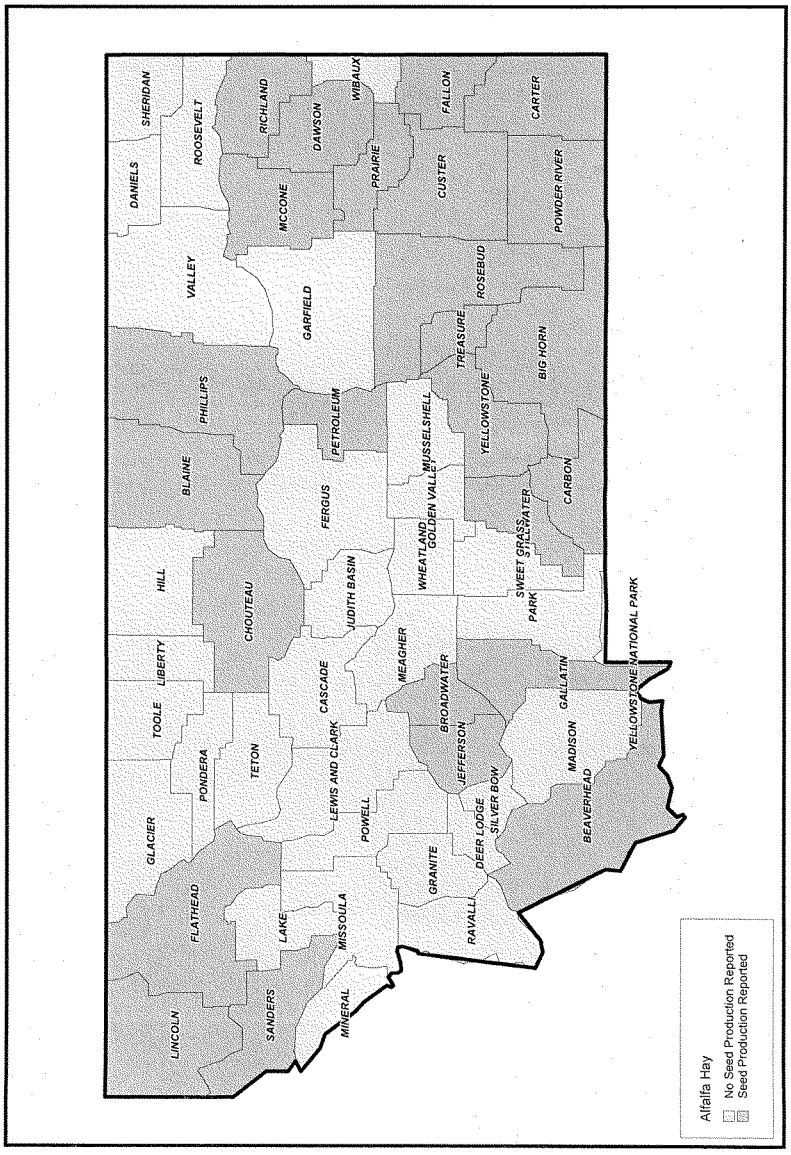
Idaho - Alfalfa Hay Counties With and Without Seed Production

Appendix B



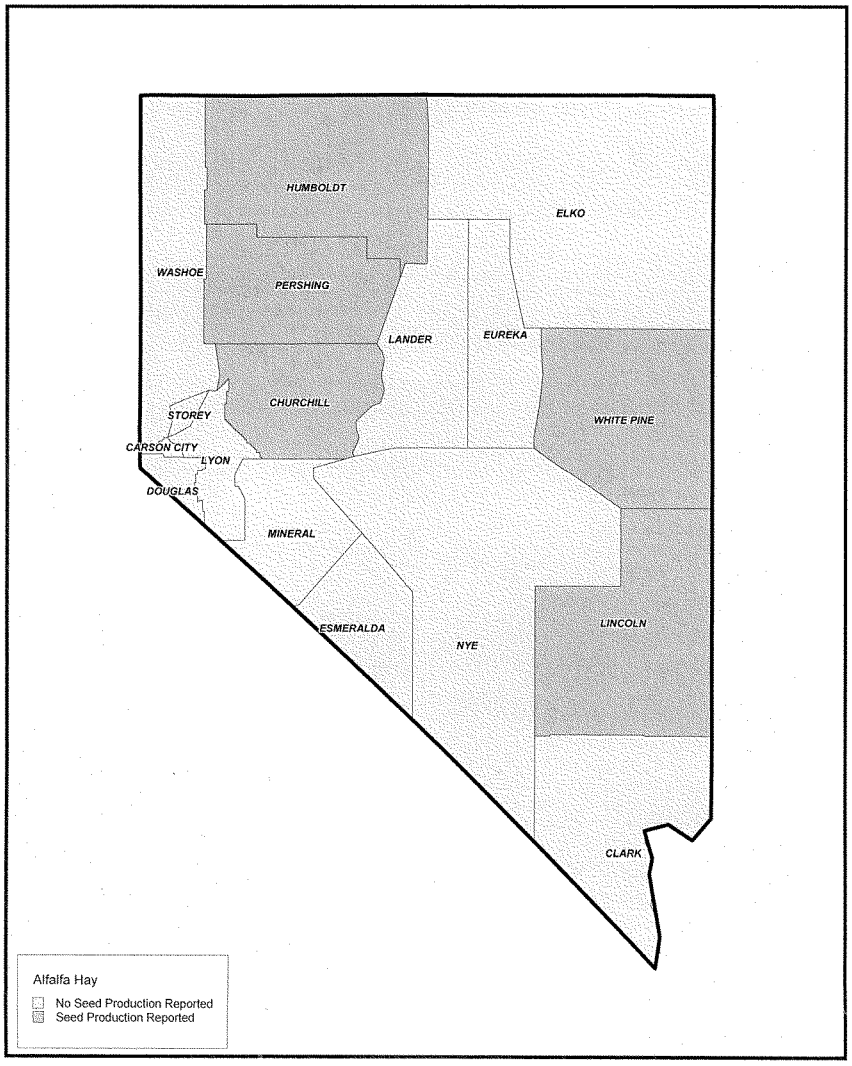
Appendix B

Montana - Alfalfa Hay Counties
With and Without Seed Production



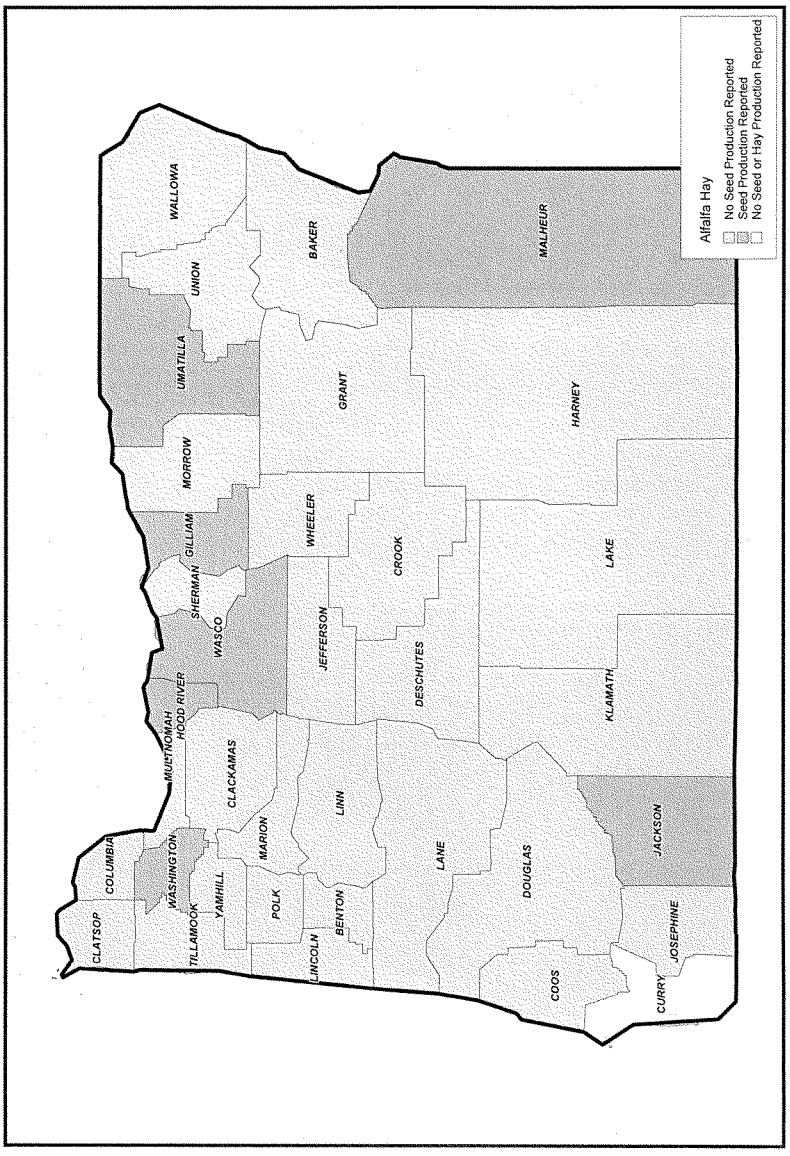
Nevada - Alfalfa Hay Counties With and Without Seed Production

Appendix B



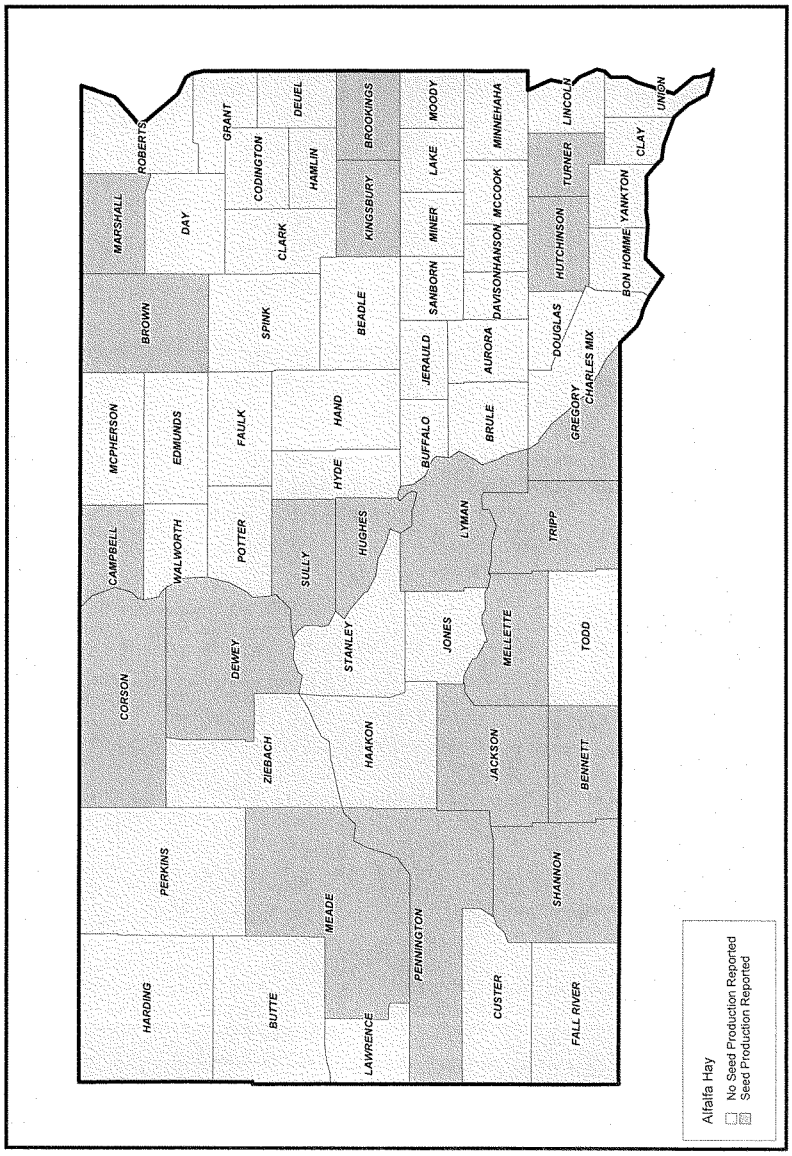
Appendix B

Oregon - Alfalfa Hay Counties
With and Without Seed Production



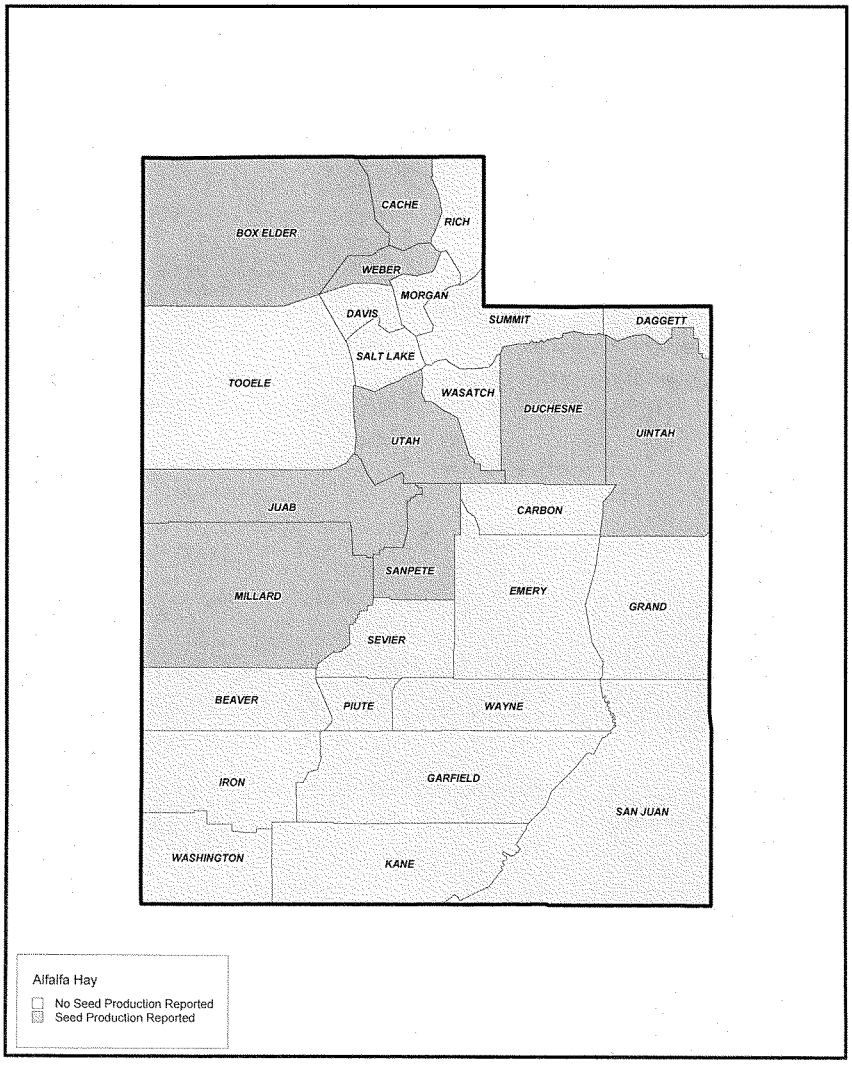
Appendix B

South Dakota - Alfalfa Hay Counties
With and Without Seed Production



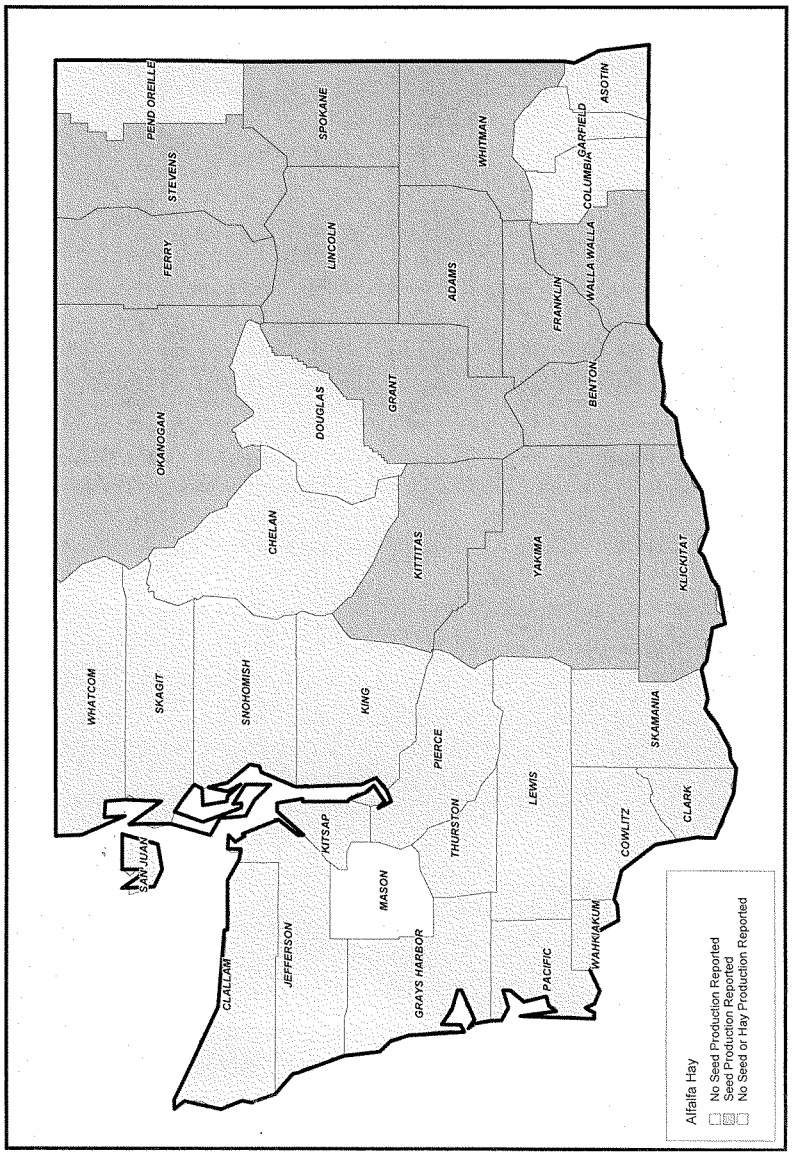
Utah - Alfalfa Hay Counties With and Without Seed Production

Appendix B



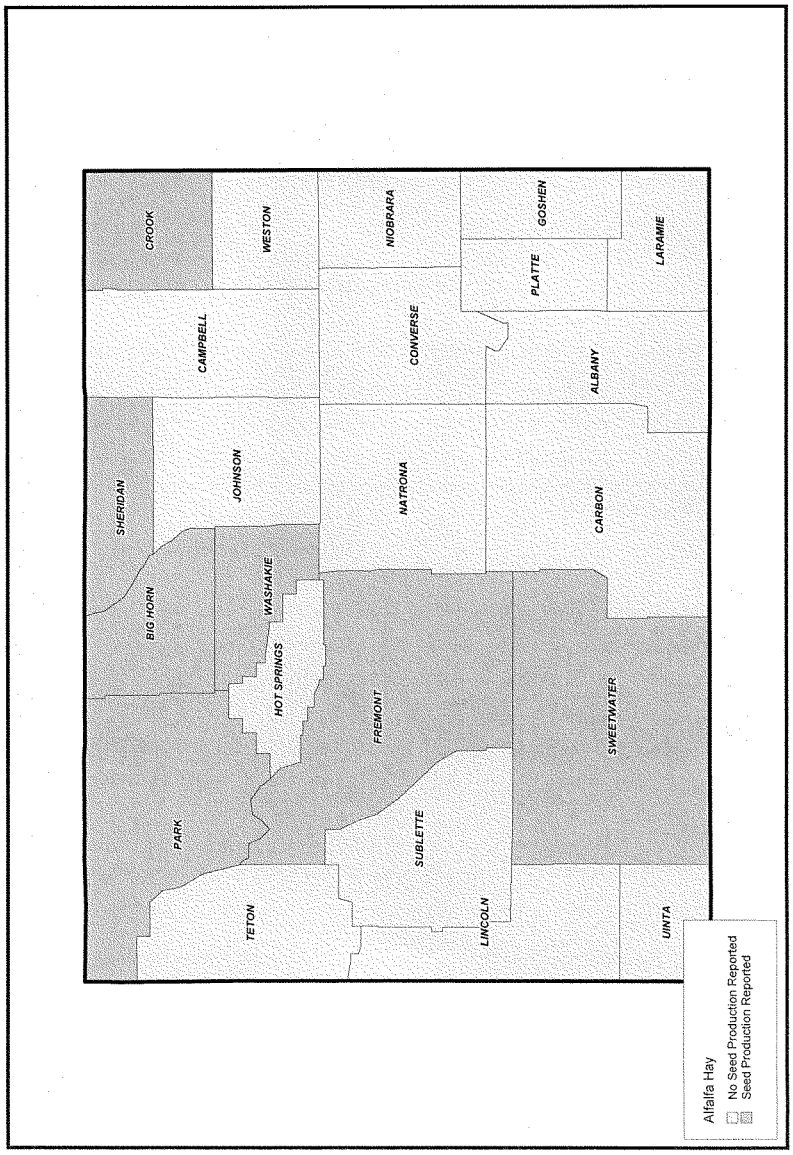
Appendix B

Washington - Alfalfa Hay Counties
With and Without Seed Production



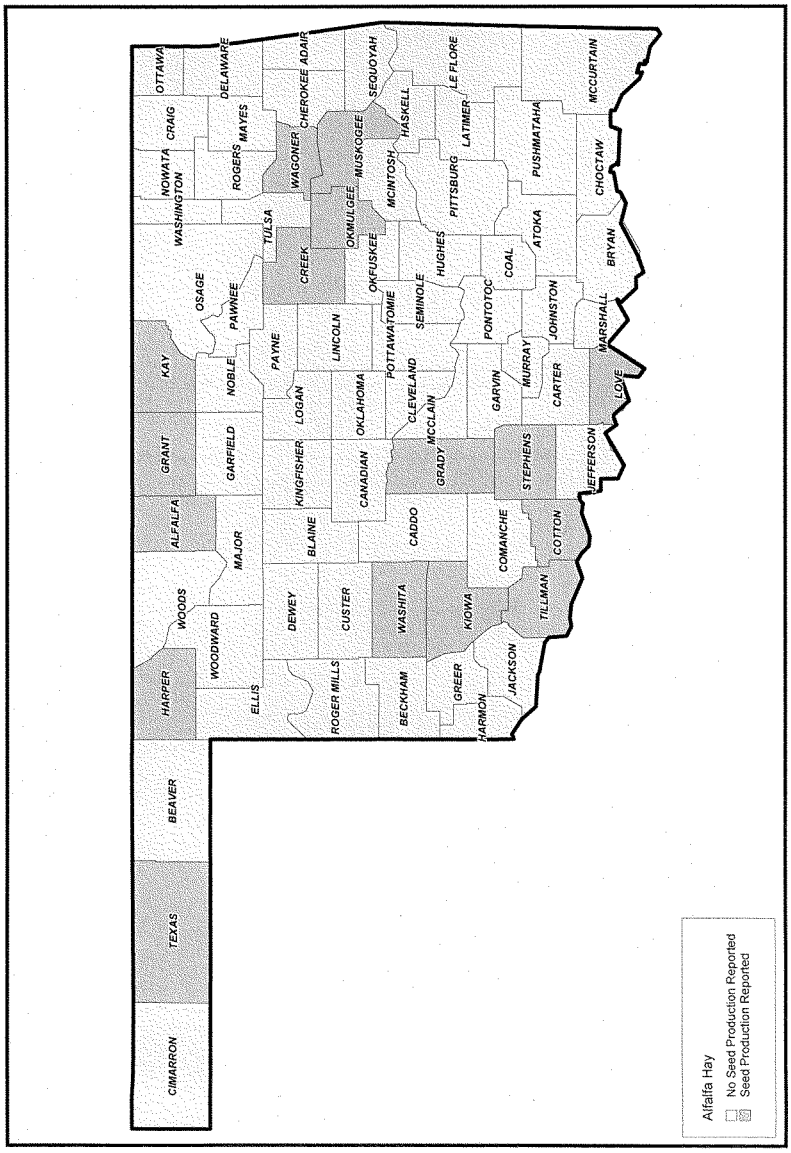
Appendix B

Wyoming - Alfalfa Hay Counties
With and Without Seed Production



Appendix B

Oklahoma - Alfalfa Hay Counties
With and Without Seed Production



Appendix C

National Alfalfa & Forage Alliance Best Management Practices for Roundup Ready® Alfalfa Seed Production



NAFA Coexistence Document — Adopted January 2008

Best Management Practices for Roundup Ready® Alfalfa Seed Production

Introduction

The genetic supplier members (hereinafter called the "Companies") of National Alfalfa & Forage Alliance (NAFA) have agreed to jointly adopt, as a minimum, the following Best Management Practices for Roundup Ready Alfalfa (RRA) Seed Production in the United States. Compliance is required under a separate and binding agreement of the Companies to each other in this commitment. Forage Genetics International (FGI) is the exclusive licensed seed producer of RRA and will require all RRA seed production sub-licensees (herein after called the "RRA Seed Contractor(s)") to become a party to this binding agreement. It is not the intent of this document to establish best management practices for the production of alfalfa seed for GE sensitive markets. Changes to this document will require a recommendation from the Companies and approval by the NAFA Board of Directors.

Roundup Ready Trait Stewardship in Seed Production

- This document establishes RRA commercial seed production policies that exceed industry standards for Certified alfalfa seed production.
- Specifically, RRA seed production practices will meet or exceed Association of Official Seed Certifying Agencies (AOSCA) standards for the seed production of Foundation Class alfalfa seed production.
- All RRA seed growers must complete RRA seed stewardship training and agree to follow the RRA seed production policies as described herein and as required by RRA seed production contracts.

RRA Seed Contractors' Responsibilities

Isolation. The RRA Seed Contractor will insure that the isolation distance between the new planting and any established conventional seed production meets the following pollinator-specific isolation requirements for RRA seed production. Note the pollinator designated applies to normal pollinating bees introduced or locally cultured for alfalfa seed production in the area. If more than one pollinator species is introduced or locally cultured, the longer minimum distance applies.

- Leaf cutter bee – 900 feet
- Alkali bee – 1 mile
- Honey bee – 3 miles

Every year the Companies will collectively sample conventional seed lots, test for adventitious presence of the Roundup Ready trait, and use isolation distance from RRA seed production to monitor the effectiveness of current isolation standards. The Companies, along with three AOSCA representatives of state crop improvement associations or their designees, will analyze the data and make recommendations for changes to required isolation distances, if appropriate.

Reporting. The RRA Seed Contractor shall report GPS coordinates of all established and planned RRA seed production fields to local state seed certification officials as early as possible, but no later than two weeks prior to planting. State officials will confirm minimum isolation and establish a state pinning map for RRA seed production. The RRA Seed Contractor must authorize state officials to report to any seed grower or seed company, on request, the isolation distance between a planned new conventional alfalfa seed field and the nearest RRA seed field. GM-trait sensitive conventional or organic alfalfa seed producers can then use this third party service to assist them in planning their field locations to meet their company's isolation or field crop history goals or the certification agent may use the data to certify a stated isolation distance. The RRA Seed Contractor shall also notify local state seed certification officials, and officials shall confirm when a RRA seed production field is terminated.

GE-free seed production zones. The RRA Seed Contractor will limit RRA seed production contracts to the following states: Arizona, California, Colorado, Idaho, Montana, Nevada, Oregon, Texas, Utah, Washington and Wyoming. The RRA Seed Contractor will also respect any GE-free alfalfa seed production zone designated as such by a consensus of local seed growers. Recognition and designation of such zones will be based on the requirements of each state. It is envisioned that the local state seed certification agency would play an active role in administering programs of this nature.

Cooperation. All seed companies are encouraged to communicate and work together individually to manage joint seed quality issues and concerns.

RRA seed grower training. The RRA Seed Contractor will require RRA stewardship training for all new RRA seed growers. The RRA seed grower will confirm having received a copy of the NAFA Best Management Practices for Roundup Ready Alfalfa Seed Production (see Appendix 2).

RRA seed grower contracts. The RRA Seed Contractor shall stipulate which bee species can be introduced for pollination and incorporate key grower stewardship requirements (as listed below) in RRA seed production contracts.

License. The RRA Seed Contractor will have an FGI license for RRA seed production, including reporting requirements for acreage planted and seed harvested, by variety.

RRA Seed Growers' Responsibilities

Monsanto Technology/Stewardship Agreement (MTA). RRA Seed Grower must sign an MTA and are bound by the terms outlined in the current Monsanto Technology Use Guide (TUG). The MTA is a limited-use license for Monsanto traits, and renews automatically each year. The TUG is updated annually.

Observe patent rights. All RRA stock seed and harvested seed contains patent-protected, Roundup Ready trait, therefore:

- All seed transfer/sale is exclusive between RRA Seed Grower and the RRA Seed Contractor; no seed may be sold by RRA Seed Grower to other parties.
- RRA Seed Grower may not save seed for any purpose as per MTA.

Observe all federal, state and local regulations. It is the RRA Seed Grower's responsibility to know and obey current federal, state and local regulations affecting their agricultural practices. Some examples are as follows:

Federal Laws and Regulations:

- Pesticide use labels and restrictions;
- U.S. Patent Rights;
- Plant Variety Protection; Federal Seed Act.
- Phytosanitary laws governing import or export of seeds and pollinators.

State Laws and Regulations:

- Noxious or prohibited weeds, pathogens or insects;
- Pesticide use labels and restrictions

Local Laws and Regulations:

- Pesticide use notifications (field posting);
- County restrictions or prohibitions on the use of biotechnology, as applicable.

Bees. RRA Seed Grower will manage pollinators to minimize pollen flow to conventional/other variety fields.

- Only contract-specified bee species can be introduced for pollination supporting RRA seed production.
- There shall be no bee domicile movement from RRA to conventional alfalfa seed fields until pollination is finished for the year.
  - Once bees are in RRA seed fields, they may only be moved among RRA fields. It is the RRA Seed Grower's responsibility to inform their pollinator contractors or bee keepers of this requirement.
- RRA Seed Grower will locate domiciles to maximize domicile distance to other varieties, to the extent reasonable and appropriate to each field.
- The main pollinator bee species will be stated on each RRA Seed Grower Contract. Isolation requirements are specific to the main pollinator species.
- If honeybees are not the contract-stipulated pollinator species, the RRA Seed Grower will discourage neighbors from keeping honeybee hives in proximity to RRA seed production. In cases where this cannot be avoided, RRA Seed Grower is required to report the incident to the RRA Seed Contractor.

Isolation. RRA Seed Grower will assist RRA Seed Contractor with field location planning prior to planting, isolation zone monitoring after planting and facilitate crop improvement inspections as requested.

- The pollinator species-specific isolation policy is as follows (minimum distance to preexisting conventional seed at planting of RRA):
  - Leaf cutter bee – 900 feet
  - Alkali bee – 1 mile
  - Honey bee – 3 miles
- Once the RRA seed field is planted, State Certification officials will visit to confirm minimum isolation distances are in place. RRA Seed Grower must cooperate with this verification process.
- If the RRA Seed Grower learns that new alfalfa seed field(s) are planned or planted in close proximity the RRA seed field, RRA Seed Grower will communicate this information to RRA Seed Contractor. Management strategies for maintaining RRA seed quality (varietal/ trait purity) can then be implemented by the RRA Seed Contractor.

Trait purity. RRA stock seed is guaranteed by the provider to have ≥90% RR plants; up to 10% non-RR plants, or "nulls", are normal and expected based on the breeding and genetics of the trait.

- Growers must apply sufficient Roundup® herbicide to kill the <10% nulls prior to 9 inches of growth in the establishment year.
- Apply only registered (labeled) Roundup brand herbicides to the field.

Weeds and in-crop volunteers. Manage weeds and volunteers using integrated weed control strategies (e.g., conventional practices supplemented with Roundup agricultural herbicide formulations applied according to the label for alfalfa seed production). Integrated weed control strategies:

- Minimize risk of weed shifts or development of tolerant weeds. Growers are required to use integrated weed control methods.
- Maintain variety true to type: RRA seed fields need non-Roundup practices to control in-crop Roundup Ready alfalfa volunteers sprouting from prior year

seed crop in carry-over fields. This is consistent with conventional alfalfa seed production practices for certified quality seeds.

Stand take-out.

- The RRA seed field must be destroyed at the expiration/termination of the seed contract. Take-out must be completed prior to first flower in the subsequent year so that seed certification inspectors can verify stand termination.
- Stand termination and volunteer management measures must be sufficient to allow seed certification inspectors to validate stand take-out and to render the alfalfa stand worthless for any unlicensed purpose or use (e.g., unlicensed seed, forage, hay or pasture production purpose).
- RRA stand take-out date and method must be reported to the RRA Seed Contractor and stand destruction verified by local crop improvement using the RRA stand take out form, or the equivalent, to report the information (see Appendix).
- Plan to use a subsequent crop that allows management of alfalfa and RRA alfalfa volunteers should they occur.

Sanitation requirements. Manage equipment to minimize seed mixture potential between different varieties and or variety types. Growers shall use dedicated equipment for planting and harvesting RRA seed production, when possible. Zero tolerance for seed admixture is not feasible under commercial production conditions; however, grower must take reasonable steps to assure that equipment is clean prior to and after use in the Roundup Ready seed field. *Examples:*

- Planter inspection, clean-down before and after use;
- Combine inspection, clean-down thoroughly before and after use;
- RRA seed bins may only be used for RRA seed; maintain physical separation of varieties in storage; inspect bins before use;
- Handle all like-trait varieties together; plan for harvest sequence of fields to maintain best separation of varieties by trait type;
- Clean all seed handling equipment to avoid mixing RRA and conventional seed;
- Return unused, unopened stock seed to the contracting seed company for credit; maintain in clean storage areas;
- When a contract harvester is used for RRA seed harvest, Growers must notify the contract harvester, in advance, that the field to be harvested is RRA.

Communication. Immediately communicate questions or concerns to the RRA Seed Contractor or to FGI.

Field records. RRA Seed Grower must record and communicate the following to RRA Seed Contractor:

- Planting date; actual acres planted; seed rate/acre; stock seed received/returned;
- Accurate field address with latitude/longitude (decimal degrees) and local field map;
- Roundup herbicide application date(s), rate(s), formulation used;
- Seed box/bin numbers used for harvest;
- Stand destruct date and methods used using the RRA stand take out form, or the equivalent, to report the information (see Appendix).

RRA Seed Contractors' Production Staff Responsibilities

- Working in close partnership with seed growers;
- Complying with binding agreements with local crop improvement organizations:
  - RRA Seed Contractor will report each field location, planting date and stand take-out date to local crop improvement organizations;
- Coating RRA stock seed purple for easy identification by seed growers;
- Recommending changes to this document, should the need arise.

Roundup Ready® and Roundup® are registered trademarks of Monsanto.

"Best Management Practices for Roundup Ready® Alfalfa Seed Production"

Coexistence Strategy Forum Steering Committee

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Reedsville, WI

Jim Cane, USDA-ARS, Logan Bee Lab
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APPENDIX 1

VERIFICATION OF STAND TAKE-OUT TO TERMINATE THE PRODUCTION OF ROUNDUP READY® ALFALFA SEED

The AGREEMENT: The Grower planted the RRA Proprietary stock seed described below on the acreage described below. In accordance with the terms of the Proprietary Seed Services Agreement for the Production of Roundup Ready Alfalfa Seed, upon expiration or termination of the agreement, the grower must take such actions as are necessary to prevent any future seed harvest or unlicensed use for hay, forage or grazing. Stand destruction must occur not later than first flower in subsequent year. Grower must notify Contracting Seed Company of each stand take-out date and method used to destroy the stand. The Contracting Seed Company must perform on-site verification that each field has been killed and Contracting Seed Company will notify local crop improvement organization of stand termination.

Use a separate form for each field or field group reported to crop improvement.

	Experimental or Variety Name:					
#	Field names	Number of Acres	Field Location: Town-Range-Section & County	Latitude / Longitude (original GPS Coordinate)	# ACRES + DATE(s) + METHOD(s)	SITE VISIT VERIFICATION DATE(s)*
1						
2						
3						
Total no. acres this contract planted:				**Total no. acres reported to be killed:**		
Seed Company representative verifying information Signature(s) Date(s)				**Seed Company representative notifying Crop Improvement** Signature(s) Date(s)		

GROWER

By:_____(signature)

By: _____(printed name)

Title:_____

Company: _____

Address: _____

_____

CONTRACTING SEED COMPANY

By:_____(signature)

By:_____(printed name)

Title:_____

Company: _____

Address: _____

_____

APPENDIX 2

These signatures confirm that the RRA Seed Grower has received the NAFA Best Management Practices for Roundup Ready® Alfalfa Seed Production

Contracting Seed Company has communicated NAFA Best Management Practices for Roundup Ready Alfalfa Seed Production to the Grower prior to initial RRA seed field planting and will update Grower annually, thereafter.

RRA Seed Contractor Representative Conducting Initial Grower Training:

PRINT NAME AND ADDRESS	SIGNATURE AND DATE
Seed Company Representative:	_____ Date: _____

RRA Seed Grower Acknowledgement of Training and/or Receipt of NAFA Best Management Practices for Roundup Ready Alfalfa Seed Production:

PRINT NAME AND ADDRESS	SIGNATURE AND DATE
Grower: Telephone number: _____	_____ Date: _____

Signature page original to be retained by RRA Seed Contractor.

Signature page copy to be retained by RRA Seed Grower.

Appendix D

Orloff, S., D.H. Putnam, M. Canevari and W.T. Lanini, *Avoiding Weed Shifts and Weed Resistance in Roundup Ready Alfalfa Systems,* University of California Division of Agriculture and Natural Resources Publication 8362 (2009)

University of California
Division of Agriculture and Natural Resources
http://anrcatalog.ucdavis.edu

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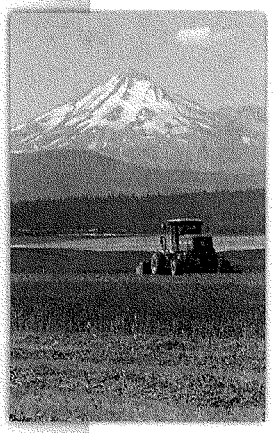
PUBLICATION 8362 / FEBRUARY 2009

Avoiding Weed Shifts and Weed Resistance in Roundup Ready Alfalfa Systems

STEVE B. ORLOFF, University of California Cooperative Extension Farm Advisor, Siskiyou County; **DANIEL H. PUTNAM,** Extension Agronomist, Department of Plant Sciences, University of California, Davis; **MICK CANEVARI,** University of California Cooperative Extension Farm Advisor, San Joaquin County; and **W. THOMAS LANINI,** UC Cooperative Extension Weed Ecologist, Department of Plant Sciences, University of California, Davis

OVERVIEW

Weeds present a continual challenge for profitable alfalfa production. The Roundup Ready (RR) production system, using transgenic alfalfa, has the potential to simplify weed management by improving broad-spectrum control of both annual and difficult-to-control perennial weeds. The use of glyphosate, in combination with transgenic crops, has proven to be a reliable weed control strategy.



However, weed species shifts and the selection for glyphosate-resistant weeds can result from the increased use of this technology if the crop is not managed properly from the outset. Aspects of the alfalfa production system both favor and discourage the occurrence of weed shifts and the evolution of resistant weeds. Alfalfa is a competitive perennial crop that is cut multiple times per year, making it difficult for most weeds to become established. On the other hand, the RR alfalfa system may be vulnerable to weed shifts and resistant weeds for several reasons: tillage typically only occurs between crops, alfalfa is produced over a wide geographical area and in large fields with a great diversity of weeds, and there is potential for long-term repeated use of a single herbicide because it is a perennial crop. In this publication we recommend an integrated weed management system designed to prevent the proliferation of tolerant or resistant weeds. Elements include crop rotation, rotations with herbicides of different modes of action (preferably soil-residual herbicides), tank mixtures, and irrigation and harvest timing. Successful adaptation of these concepts into production systems would assure the long-term effectiveness and sustainability of the Roundup Ready system in alfalfa. A preemptive approach is warranted; these strategies should be employed before weed shifts and weed resistance occur.

IMPORTANCE OF WEED CONTROL IN ALFALFA

Alfalfa, the queen of forages, is the principal forage crop in the United States and frequently the third most important crop in value. It is a vital component of the feed ration for dairy cows and is a principal feed for horses, beef cattle, sheep, and other livestock. Because animal performance depends upon the palatability and nutritional value of alfalfa, livestock managers, especially those in the dairy and horse industry, expect high-quality hay. Although many factors influence quality, the presence of grassy and broadleaf weeds (of low forage quality) plays a significant role in reducing the feeding value of hay throughout the United States. Weeds that accumulate nitrates or are poisonous to livestock are also a major concern in alfalfa, since poisonous weeds sicken or kill animals every year (Puschner 2005). Most livestock producers demand weed-free alfalfa for optimum quality and maximum animal performance.

Weed-free alfalfa can be difficult to achieve, whether using nonchemical methods or conventional herbicides. Typically, no single herbicide controls all weeds present in a field, and some weeds—especially perennials—are not adequately controlled with any of the currently registered conventional herbicides. Cultural practices such as modifying harvest schedules, grazing, time of planting, and use of nurse crops such as oats (*Avena sativa* L.) help suppress weeds; however, these practices are almost never entirely effective and some of them suppress alfalfa seedling growth. In addition to being difficult to achieve, complete weed control in alfalfa is costly. Alfalfa growers continually seek ways to enhance the level of weed control while minimizing costs.

Roundup Ready technology was a major development in alfalfa weed control, providing growers with a useful weed management tool and a means to deal with some of the most difficult-to-control weed species.

THE ROUNDUP READY ALFALFA TECHNOLOGY

Glyphosate (Roundup) is generally considered the most effective broad-spectrum post-emergence herbicide available. The first commercially available glyphosate-resistant crops were soybean, canola, cotton, and corn, which were released in 1996, 1997, 1997, and 1998, respectively. Glyphosate-resistant or Roundup Ready alfalfa (RR alfalfa) was developed through biotechnology in late 1997 and became commercially available in the fall of 2005. This technology imparts genetic resistance to glyphosate by inserting a single gene from a soil bacterium into alfalfa. These biotechnology-derived alfalfa plants have an altered enzyme that allows them to tolerate a glyphosate application while susceptible weeds are killed. Glyphosate resistance is the first commercially available, genetically engineered (GE) trait in alfalfa.

This technology was a major development in alfalfa weed control, providing growers with a useful weed management tool and a means to deal with some of the most difficult-to-control weed species. Researchers have evaluated its effectiveness as a weed control strategy (Canevari et al. 2007; Sheaffer et al. 2007; Steckel et al. 2007, Van Deynze et al. 2004). The advantages and disadvantages of this technology have been reviewed (Van Deynze et al. 2004). Glyphosate was found to be especially effective for weed control in seeding alfalfa (Canevari et al. 2007). Glyphosate typically causes no perceptible crop injury, is much more flexible and less restrictive in application, and provides superior weed control across a range of weed species when compared with other currently used herbicides. One of the greatest advantages of this technology is that it provides a tool for suppressing perennial weeds such as dandelion (*Taraxacum officinale*), yellow nutsedge (*Cyperus esculentus* L.), bermudagrass (*Cynodon dactylon* (L.) Pers.), and quackgrass (*Elytrigia repens* (L.) Nevski) that have not been adequately controlled with conventional practices.

After deregulation of this trait in 2005, over 300,000 acres of RR alfalfa were planted in the United States, about 1.4 percent of U.S. acreage. (For equivalents between U.S. and metric systems of measurement, a conversion table is provided at the end of this publication.) However, in the spring of 2007, further plantings were suspended pending the outcome of a legal challenge and further environmental analysis by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS). There were two key issues in this process: the possibility of contamination of organic and conventional alfalfa through the adventitious presence of the gene, and the possibility of a greater level of weed resistance due to the adoption of the Roundup Ready technology in alfalfa (USDA 2008).

Grower experience in commercial fields following deregulation confirmed many of the benefits that early research had suggested in terms of the efficacy and safety of the RR system (Van Deynze et al. 2004). Growers have generally found that this technology is easy to use and provides superior weed

control and improved forage quality in many cases compared with conventional herbicides. However, no new technology is a panacea, and, like other weed control strategies, RR alfalfa has its limitations. An important limitation of this new weed-management system is the potential for weed shifts and weed resistance. This publication discusses techniques that are available to manage the possibility of weed shifts and weed resistance occurring in Roundup Ready alfalfa weed control systems.

WEED SHIFTS AND WEED RESISTANCE

Change in weed populations as a result of repeated use of a single herbicide is not a new phenomenon. Such changes result from shifts in the weeds present from susceptible to tolerant species, or conversion of a population within a species to resistant individuals, as a consequence of selection pressure (Holt and LeBaron 1990; Prather et al. 2000).

Weed Shift

A weed shift refers to a change in the relative abundance or type of weeds as a result of a management practice (fig. 1). The management practice could be herbicide use or any other practice such as tillage, manure application, or harvest schedule that brings about a change in weed species composition.

In the case of chemical weed control, no single herbicide controls all weeds, as weeds differ in their susceptibility to an herbicide. Susceptible weeds are largely eliminated over time with continued use of the same herbicide. This allows inherently tolerant weed species to remain, which often thrive and proliferate with the reduced competition. As a result, there is a gradual shift to tolerant weed species when practices are continuously used that are not effective against those species. A weed shift does not necessarily have to be a shift to a different species. For example, with a foliar herbicide without residual activity like glyphosate, there could also be a shift within a weed species to a late-emerging biotype that emerges after application. In the case of weed shifts, the total population of weeds does not necessarily change as a result of an herbicide or an agronomic practice; these practices simply favor one species (or biotype) over another.

Weed Resistance

In contrast to a weed shift, weed resistance is a change in the population of weeds that were previously susceptible to an herbicide, turning them into a population of the same species that is no longer controlled by that herbicide (fig 2).

Figure 1. Weed shifts due to herbicide application. A weed species shift occurs when both susceptible and tolerant weed species are present in a field. After continued use of a single herbicide, the susceptible weed species is nearly eliminated. The tolerant weed species survives and proliferates, eventually becoming the prevailing species. In this example, a shift to a broadleaf weed is favored by use of a grass herbicide.

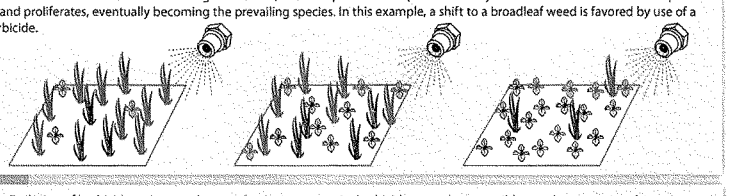
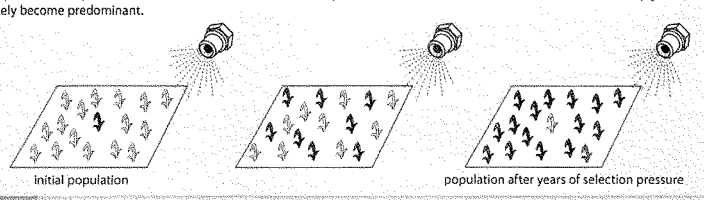


Figure 2. Evolution of herbicide resistance due to selection pressure. An herbicide controls susceptible weeds, preventing them from reproducing and leaving only those individuals carrying the genes for resistance. Typically an extremely small percentage of the weed population initially possesses the genes for resistance. These altered genes are thought to exist in weed populations at very low frequencies. As repeated use of an herbicide controls the susceptible individuals, the resistant weeds continue to multiply and ultimately become predominant.



While weed shifts can occur with any agronomic practice (crop rotation, tillage, frequent harvests, or use of particular herbicides), the evolution of weed resistance is only the result of continued herbicide application. The use of a single class of herbicides continually over time creates selection pressure so that resistant individuals of a species survive and reproduce, while susceptible ones are killed.

Which Is More Important, Weed Shifts or Weed Resistance?

A weed species shift is far more common than weed resistance, and ordinarily takes less time to develop. If an herbicide does not control all the weeds, the tendency is to quickly jump to the conclusion that resistance has occurred. However, a weed shift is a far more likely explanation for weed escapes following an application of glyphosate. See table 1 for a list of weeds sometimes found in alfalfa fields that are tolerant to or difficult to control with glyphosate.

Table 1. Annual weeds encountered in alfalfa fields that are potential candidates for weed shifts in continuous glyphosate systems

Latin name	Common name
*Brassica nigra**	black mustard
Chenopodium album†	lambsquarters
Echinochloa colona†	junglerice
*Epilobium brachycarpum**	Willowherb, panicle willowherb, panicle
*Eragrostis**	lovegrass
Erodium spp.†	filaree
Lamium amplexicaule†	henbit
Lolium multiflorum†‡	ryegrass
*Malva parviflora**	malva (cheeseweed)
Polygonum convolvulus†	wild buckwheat
Polygonum spp.†	knotweeds
Portulaca oleracea†	purslane
Sonchus oleraceus†	annual sowthistle
*Trifolium spp.**	clover
*Urtica urens**	burning nettle

Note: This table includes weeds that are listed as susceptible on the label but are difficult to control and weeds which are not controlled by glyphosate.
*Glyphosate-tolerant weeds—not listed as controlled on product label.
†Difficult to control weeds.
‡Glyphosate-resistant biotype has been confirmed.

Are Weed Shifts or Weed Resistance Linked Only to Genetically Engineered Crops?

A common misconception is that weed resistance is intrinsically linked to genetically engineered (GE) crops. However, this is not correct. The occurrence of weed shifts and weed resistance is not unique to genetically engineered crops. Weed shifts and resistance are caused by the practices that may accompany a GE crop (for example, repeated use of a single herbicide), not the GE crop itself. Similarly, some people believe that herbicide resistance is transferred from the GE crop to weed species. However, unless a crop is genetically very closely related to a naturally-occurring weed, weed resistance cannot be transferred from crop to weed. In the case of alfalfa, there are no known wild plants that cross with alfalfa, so direct transfer of herbicide resistance through gene flow to weedy species will not occur. However, the glyphosate-tolerant genes from RR alfalfa can be transferred to feral (wild) alfalfa plants if cross pollination occurs.

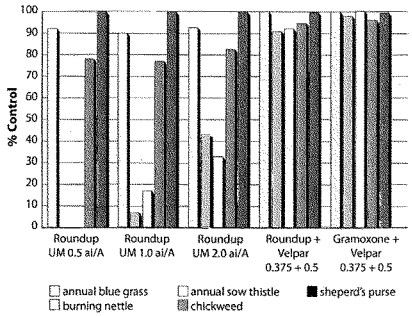
Link to Management Practices

The development of weed shifts or the evolution of weed resistance in cropping systems is primarily a result of management practices, not the crop itself. Continued use of the same management practice, in this case the use of a single herbicide, increases the probability of a weed shift or the evolution of resistant weeds as a result of constant selection pressure. For example, if the herbicide diuron (Karmex) is used alone for several years in established alfalfa, susceptible weeds are controlled. However, there is likely to be an increase in tolerant weeds such as common groundsel (*Senecio vulgaris*), Persian speedwell (*Veronica persica*), and others. Similarly, if imazethapyr (Pursuit) is used repeatedly for several years without rotating with other herbicides, there is likely to be an increase in the population of prickly lettuce (*Lactuca serriola*), annual sowthistle (*Sonchus oleraceus*), and many grassy weeds that are not controlled by this herbicide. Rigid ryegrass (*Lolium rigidum*) and horseweed (*Conyza canadensis*) resistance to glyphosate was the outcome of repeated glyphosate applications in California orchards and noncrop settings, respectively. Weed shifts and weed resistance are not new; evolved resistance was first reported in the 1970s and now occurs with a range of herbicide classes (Holt and LeBaron 1990; Heap 1999; Heap 2008).

RR Crops Present a Challenge

Transgenic herbicide-resistant crops do, nonetheless, have greater potential to foster weed shifts and resistant weeds since a grower is more likely to use a single herbicide repeatedly in herbicide-resistant crops such as RR alfalfa. Additionally, the accumulation of acreage of different RR crops (corn, soybean, and cotton) could increase the potential for weed shifts or weed resistance in cropping systems utilizing RR crops. This is because the probability of repeated use of the

Figure 3. Weed control 69 days after treatment in an established stand of Roundup Ready alfalfa, San Joaquin County, California, 2004.



same herbicide is higher and the potential applied acreage (and therefore the size and genetic diversity of the weed population) is greater. Fortunately, there are simple methods available to prevent weed shifts and weed resistance from occurring.

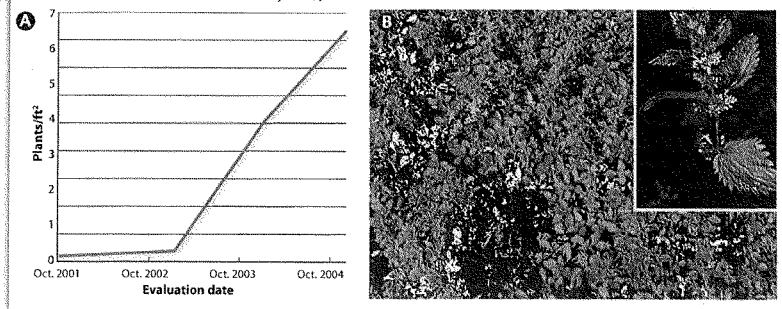
In studies conducted in San Joaquin County, California, weeds shifts were found to occur during the first few years of use when glyphosate-tolerant weeds were present (Van Deynze et al. 2004). Annual bluegrass and shepherd's purse were adequately controlled with glyphosate, whereas chickweed control was about 80 percent and burning nettle and annual sowthistle were not adequately controlled with any of the glyphosate rates (fig. 3). During the 3 years of this field trial, when glyphosate was used repeatedly, there was a gradual weed species shift away from annual bluegrass and shepherd's purse to higher populations of burning nettle and annual sowthistle (figs. 4A and 4B). A tank mix of glyphosate and Velpar, or a rotation to Velpar and Gramoxone, was needed to adequately control all weed species at this location.

To our knowledge there have been no documented cases of weed resistance in alfalfa during the first 3 years of RR alfalfa production (2005 to 2008) in the United States.

WEED SHIFTS AND RESISTANCE WITH RR ALFALFA

The possibility of weed shifts and weed resistance is a concern with RR alfalfa. This is due to its perennial growth habit, its long stand life, and the potential for repeated use of a single herbicide over several years without crop rotation. Although some stands last 3 to 4 years, it is common in many areas of the United States to keep an alfalfa stand in production for 5 to 7 years or longer. If the rotation crop (e.g. a grain crop) is not treated with an herbicide, an even longer period of time without herbicide diversity could occur. In this instance, weed populations could slowly return to preglyphosate composition, but the new species or resistant biotypes would not disappear. In areas where alfalfa is rotated with transgenic RR corn, cotton, or soybean varieties, this

Figure 4. (A): Increase in burning nettle population in Roundup Ready alfalfa with repeated annual applications of glyphosate alone, San Joaquin County, California, 2006. **(B):** Plot overtaken with burning nettle after 3 years of continual glyphosate use. *Photos:* Mick Canevari; insert, J.M. DiTomaso, from DiTomaso and Healy 2007, p. 1565.



again could result in a prolonged time period where a single herbicide is used repeatedly.

There are aspects of the alfalfa production system that both favor and discourage the development of weed shifts and the evolution of resistant weeds.

Attributes of Alfalfa That Favor Weed Shifts and Resistance

First, crop rotation opportunities with a perennial crop like alfalfa are significantly reduced compared with annual cropping systems. Mechanical weed control, such as cultivation, is impractical in a solid-seeded perennial crop like alfalfa, and hand weeding is not economical. Alfalfa is grown over extensive acreage in the United States and fields can be large in size; therefore, the overall weed flora available for selection of resistant traits or for weed shifts is plentiful. Perennials like alfalfa, if sprayed repeatedly with the same herbicide, are likely candidates for weed shifts and weed resistance.

Attributes of Alfalfa That Discourage Weed Shifts and Resistance

On the other hand, many weeds do not flourish in an alfalfa field due to its perennial nature and the competitiveness of the crop after establishment. Alfalfa is an aggressive competitor with most weeds, which fail to establish in alfalfa fields due to the crop's vigorous growth and shading ability. In addition, many weed species do not tolerate the frequent cutting that occurs in alfalfa fields. The lack of soil disturbance once the alfalfa stand is established also reduces opportunities for germination of some weed species. Furthermore, the interval between alfalfa cuttings is short enough that seed production for many weeds is reduced compared with annual crops that allow completion of the weeds' life cycles.

Risk of Resistance Generally Lower with Glyphosate Than with Other Herbicides

Weed shifts or resistant weeds are unavoidable and will occur eventually with any herbicide used repeatedly, and the same is true with the use of glyphosate (Heap 1999). Fortunately, resistance to glyphosate is not as common as resistance to many other herbicides, such as acetolactate synthase (ALS) and acetyl-CoA carboxylase (ACCase) herbicides that have a single binding site and single target enzyme mechanisms of action (Heap 2008). The relatively low rate of resistance in weeds to glyphosate relative to the widespread use of this chemical has not been fully explained, but may be due to the number or frequency of mutations that may be required to confer resistance to glyphosate. Two resistance mechanisms, a weak target site mutation, and a reduced glyphosate translocation mechanism have been documented in weed species that have evolved resistance to this herbicide (Powles and Preston 2006).

Regardless of the mechanism, weed resistance to glyphosate is not as common as resistance to other herbicides. However, cases of weed resistance to glyphosate have been documented and are increasing. There is a range of species across the world with documented resistance to glyphosate (table 2). Fortunately, most of these species are not common in alfalfa fields. Two weed species in particular have evolved resistant populations in California: *Lolium* spp. (ryegrass) and *Conyza* sp. (marestail). The latter is not important in alfalfa, but ryegrass is frequently found in alfalfa fields. Glyphosate-resistant ryegrass is increasing in the Sacramento Valley and northern San Joaquin Valley of California and may become problematic during fall stand establishment of RR alfalfa.

Weed shifts and/or weed resistance have occurred with the other transgenic RR crops released before RR alfalfa (Duke and Powles 2008). Weed resistance is of greater concern than weed shifts and has occurred in RR soybean, cotton, and corn in less than a decade after their initial release (see table 2). Alfalfa growers can learn from experience with these crops and in noncrop areas as a preemptive measure to avoid, or at least minimize, the problems with weed shifts and weed resistance. These problems are sure to occur in alfalfa if proper weed management practices are not followed.

Alfalfa growers can learn from experience with other RR crops and in noncrop areas as a preemptive measure to avoid, or at least minimize, the problems with weed shifts and weed resistance.

WEED MANAGEMENT PRINCIPLES TO REDUCE WEED SHIFTS AND RESISTANCE IN ALFALFA

Glyphosate-resistant crops have provided growers with an easy-to-use, low-cost, and effective weed management tool. However, the effectiveness of weed control systems using RR crops can make growers complacent in their weed control practices. Even though this technology is highly effective, growers must follow sound weed management

principles to prevent short- or long-term weed shifts or weed resistance from occurring. This includes weed identification, crop rotation, attention to application rate, proper timing of application, herbicide rotation, and tank mixtures.

Weed Identification

Effective weed management practices begin with proper identification to assess the competiveness of the weeds present and to select the proper herbicide if one is needed. A weed management strategy to prevent weed shifts and weed resistance requires knowledge of the composition of weeds present. Identification of young seedlings is particularly important because seedling weeds are easier to control. Resources for weed identification can be found at the UC IPM Web site (http://www.ipm.ucdavis.edu/PMG/weeds_common.html) and at the UC Weed Research and Information Center Web site (http://wric.ucdavis.edu/information/information.html).

Table 2. Glyphosate-resistant weed populations

Resistant weed	Common name	Location of resistant populations	Situation(s)	Year first reported
UNITED STATES			(In the U.S.)	
Amaranthus palmeri	Palmer amaranth	Arkansas, Georgia, North Carolina, Mississippi, Tennessee	corn, cotton, soybean	2005
Amaranthus rudis	common waterhemp	Illinois, Kansas, Minnesota, Missouri	corn, soybean	2005
Ambrosia artemisiifolia	common ragweed	Arkansas, Kansas, Missouri	soybean	2004
Ambrosia trifida	giant ragweed	Arkansas, Indiana, Kansas, Minnesota, Ohio, Tennessee	cotton, soybean	2004
Conyza bonariensis	hairy fleabane	California	roadsides	2007
Conyza canadensis	horseweed (marestail)	17 states including California	cotton, nurseries, roadsides (in CA), soybean	2000
Lolium multiflorum	italian ryegrass	Mississippi , Oregon	cotton, orchards, soybean	2004
Lolium rigidum	rigid ryegrass	California	orchards	1998
Sorghum halepense	Johnsongrass	Arkansas	soybean	2007
WORLD			(In the world)	
Conyza bonariensis	hairy fleabane	Brazil, Colombia, South Africa, Spain	corn, orchards, soybean, vineyards, wheat	2003
Conyza canadensis	horseweed (marestail)	Brazil, China, Czech Republic, Spain	orchards, soybean, railways	2005
Digitaria insularis	sourgrass	Brazil , Paraguay	soybean	2006
Echinochloa colona	junglerice	Australia (New South Wales)	cropland	2007
Eleusine indica	goosegrass	Colombia , Malaysia	cropland , orchards	1997
Euphorbia heterophylla	wild poinsettia	Brazil	soybean	2006
Lolium multiflorum	Italian ryegrass	Argentina, Brazil, Chile, Spain	cropland orchards, soybean	2001
Lolium rigidum	rigid ryegrass	Australia, France, South Africa, Spain	asparagus, orchards, railways, sorghum, vineyards, wheat	1996
Plantago lanceolata	buckhorn plantain	South Africa	orchards, vineyards	2003
Sorghum halepense	Johnsongrass	Argentina	soybean	2005
Urochloa panicoides	liverseedgrass	Australia (New South Wales)	sorghum, wheat	2008

Source: International Survey of Herbicide Resistant Weeds, adapted from Heap 2008.

Frequent Monitoring for Escapes

It is difficult to detect an emerging weed shift or weed resistance problem if fields are not frequently monitored for weeds that escape current weed management practices. Identification and frequent monitoring can detect problem weeds early and guide management practices, including herbicide selection, rate, and timing.

Herbicide Rate and Timing

It is important to use the appropriate rate and timing for the weeds present. For example, some weeds that are considered somewhat tolerant to glyphosate (cheeseweed, filaree, and purslane) can be controlled effectively in seedling alfalfa with glyphosate, provided the proper rate is used and the application is made when the weeds are very small. Research in Nebraska over a 7-year period (Wilson 2004) demonstrated a rapid increase in lambsquarters when a low rate of glyphosate (0.5 lb ai/acre) was applied, but a higher rate (1.0 lb ai/acre) successfully controlled this weed. Just like with traditional weed management programs, the grower must be sure to use the recommended rate for the weed species present and treat at the appropriate time when the weeds are still small.

Crop Rotation

One of the most effective practices for preventing weed shifts and weed resistance is crop rotation, which allows growers to modify selection pressure imposed on weeds. Continuous (also called back-to-back) alfalfa is not recommended for other agronomic reasons, but especially would be ill advised when it comes to management of resistance and weed shifts. Crops differ in their ability to compete with weeds; some weeds are a problem in some crops, while they are less problematic in others. Rotation therefore would not favor any particular weed spectrum. Crop rotation also allows the use of different weed control practices, such as cultivation and application of herbicides with different sites of action. As a result, no single weed species or biotype should become dominant. The effectiveness of crop rotation to manage weed shifts and resistance is substantially reduced if another RR crop (such as corn or cotton) is planted in rotation with RR alfalfa, since the same herbicide and selection pressure would likely occur.

Using an effective herbicide with a different mode of action from the one to which the weeds are resistant controls both the susceptible and resistant biotypes, thus preventing reproduction and slowing the spread of the resistant biotype.

Agronomic Practices

In addition to crop rotation, several management practices may have an impact on the selection of problem weed populations. If problem weeds germinate at a specific time of year, crop seeding date can be shifted to avoid these weed populations, allowing a vigorous alfalfa crop to develop that is capable of outcompeting weeds. Delaying irrigation after alfalfa cutting can reduce germination of certain summer annual weeds. However, this practice only works on some soil types, and water stress in alfalfa can reduce yields. Harvest management can, in some cases, assist in eliminating or suppressing problem weed populations, but harvests must occur before weed seed production to prevent weed proliferation.

Rotation of Herbicides

Weed shifts occur because herbicides are not equally effective against all weed species and herbicides differ greatly in the weed spectrum they control. A weed species that is not controlled will survive and increase in density following repeated use of one herbicide. Therefore, rotating herbicides is recommended. Rotation of herbicides reduces weed shifts, provided the rotational herbicide is highly effective against the weed species that is not controlled with the primary herbicide. The grower should rotate to an herbicide with a complimentary spectrum of weed control, along with a different mechanism of action and therefore a different herbicide binding site. Weed susceptibility charts are useful to help develop an effective herbicide rotation scheme (Canevari et al. 2006). In addition, publications on herbicide chemical families are available to assist growers in choosing herbicides with different mechanisms of action (Retzinger and Mallory-Smith 1997).

Rotating herbicides is also an effective strategy for resistance management. Within a weed species there are different biotypes, each with its own genetic makeup, enabling some of them to survive a particular herbicide application. The susceptible weeds in a population are killed, while the resistant ones survive, set seed, and increase over time. Using an effective herbicide with a different mode of action from the one to which the weeds are resistant, however, controls both the susceptible and resistant biotypes. This prevents reproduction and slows the spread of the resistant biotype.

Herbicide Tank Mixtures

For the same reasons that rotating herbicides is effective, tank mixing herbicides is also recommended. The key is to select tank mix partners that have different target sites and that compliment each other so that, when combined, they provide complete or nearly complete weed control.

RECOMMENDED WEED MANAGEMENT PROGRAM FOR RR ALFALFA

The cost of RR alfalfa seed, including the technology fee, is generally twice or more than that of conventional alfalfa seed. Naturally, growers will want to recoup their investment as quickly as possible. Therefore, considerable economic incentive exists for the producer to rely solely on repeated glyphosate applications alone as a weed control program. Some producers may even be inclined to shave the rates to the minimum amount that would provide acceptable weed control. While relying solely on glyphosate and shaving rates may provide satisfactory results in the short term, it is a risky practice in the long run as it will accelerate weed species shifts and the evolution of resistant weeds. Sound weed management practices should be employed to maintain the effectiveness of the RR technology.

Roundup Ready alfalfa is still a relatively new technology, so there has been limited field experience with it to date. The following are some suggestions to consider based upon proven resistance management strategies, our understanding of alfalfa production practices, and our initial experience with RR alfalfa. Ultimately, growers and pest control advisors hold the key to avoiding weed shifts and resistance by reducing selection pressure, which is accomplished by developing a weed management program that does not rely solely on the continuous use of glyphosate. Any management practice that reduces the selection pressure (in this case, the selection pressure imposed by continual use of the same herbicide) will help avoid weed species shifts and resistance.

For Seedling Alfalfa, Use Glyphosate Alone or in a Tank Mix Combination

Seedling alfalfa is most vulnerable to weed competition because weeds are often more vigorous and competitive than young alfalfa. Additionally, complete weed control in seedling alfalfa is often difficult to achieve and frequently requires tank mixes of different herbicides to control the broad spectrum of weeds found in an individual field. Yield and stand loss from weed competition, and injury from conventional herbicides, are usually far greater in seedling than in established alfalfa. Numerous field trials throughout the United States have proven the effectiveness of RR alfalfa for stand establishment. Superior weed control with no perceptible alfalfa injury has occurred in most studies. Therefore, it is only logical to use glyphosate for weed control in RR seedling alfalfa for the cost savings, improved weed control, reduced crop injury, superior stand establishment, and the elimination of the small percentage of alfalfa seedlings (commonly called nulls) that do not carry the RR gene. Delayed removal of these nulls may cause weed control problems in the future by creating open spaces for weeds to grow.

Ordinarily, 1.0 pound per acre active ingredient of glyphosate is sufficient for weed control during the seedling period. However, a higher rate may be needed if the field contains some of the more tolerant weeds listed in table 1. A tank mix may be advised if especially-difficult-to-control weeds are present. For example, a tank mix of glyphosate with imazamox (Raptor) or imazethapyr (Pursuit) may be advised if burning nettle is present, or a tank mix with clethodim (Prism) will be necessary if the field or surrounding area is known to have glyphosate-resistant ryegrass.

Rotate or Tank Mix Herbicides at Least Once During the Life of an Alfalfa Stand

Alfalfa stand life varies considerably throughout the western United States depending on the production area, grower practice, and the existence of profitable rotation crop options. A stand life of 3 to 5 years is common in the Central Valley of California and other warm, long growing-season areas of the Southwest. A stand life of 5 to 7 years is common in much of the Northwest, and some alfalfa stands remain in production in excess of 10 years. As suggested by the principles outlined above, it is unwise to rely solely on glyphosate applications for weed control throughout the life of a transgenic alfalfa field. This practice would encourage weed shifts and resistance, and over time weed control would diminish in most cases. Once an herbicide is rendered ineffective as a result of resistant weeds, its usefulness as a weed control tool may be greatly diminished. After a resistant weed population has gained a foothold, it is practically impossible to eliminate it due to the presence of a weed seedbank.

Most alfalfa producers apply an herbicide to alfalfa during the dormant season to control winter annual weeds that infest the first cutting. It is strongly recommended that growers not rely solely on glyphosate for their winter weed control program for the duration of the stand. They should rotate to another herbicide or tank mix at least once in the middle of the life of a stand, and perhaps twice if the stand life is over 5 years (table 3).

Use an Herbicide with a Different Mode of Action

Fortunately, all of the herbicides currently registered in alfalfa—and there are several to choose from—have

Table 3. Comparison of weed management strategies for glyphosate-resistant alfalfa using continuous glyphosate applications versus a recommended approach where glyphosate is rotated with other herbicides during a 4-year alfalfa stand

Year	Objective	Season	Continuous glyphosate strategy	Rotational herbicide strategy
Seedling	control weeds that compete during stand establishment	fall	glyphosate	glyphosate
1	control late-emerging weeds during establishment	winter (late)	glyphosate	glyphosate*
	summer annual weed control may not be needed first year	spring		
		summer		
		fall		
2	control winter annual weeds and/or pre-emergence control of summer weeds	winter	glyphosate	soil residual herbicide or tank mix* of soil residual herbicide with glyphosate†
	summer annual weed control/dodder	spring		
		summer	glyphosate	
		fall		
3	control winter annual weeds and/or pre-emergence control of summer weeds	winter	glyphosate	soil residual herbicide or tank mix* of soil residual with glyphosate†
	control summer annual grassy weeds/ dodder	spring	glyphosate	
		summer (mid)	glyphosate	
		fall		
4	control winter annual weeds	winter	glyphosate	glyphosate
	control summer annual grassy weeds/ dodder	spring	glyphosate	
		summer (mid)	glyphosate	glyphosate
	(stand take-out)	fall (late)	tillage and/or 2,4-D + dicamba as necessary	tillage and/or 2,4-D + dicamba as necessary
(4 years)	**Total number of glyphosate applications**		10	4–6

Note: A combination of soil residual herbicides and different modes of action is recommended to prevent weed shifts and herbicide resistance. These are examples only—appropriate strategies should be modified for different regions and weed pressures.

*Tank mixing with another herbicide is advised if significant populations of glyphosate, tolerant weeds such as burning nettle are present.

†Soil residual herbicide (depending on location and weed spectrum, use hexazinone, diuron, or metribuzin) for pre-emergence control of winter annual weeds. An application of a dinitroaniline herbicide (pendimethalin or trifluralin) applied at this time will control summer annual grassy weeds.

a different target site of action than does glyphosate. The soil-residual herbicides applied during the dormant season to established alfalfa [such as hexazinone (Velpar), diuron (Karmex), metribuzin (Sencor), and pendimethalin (Prowl)] would be appropriate herbicides for a rotation or tank-mix partner. The rotation herbicide or tank-mix partner of choice depends on the weeds present in the field and their relative susceptibility to the herbicides. Paraquat (Gramoxone) is another candidate for rotation, but paraquat, like glyphosate, lacks residual activity and is applied late in the dormant season. By rotating paraquat with glyphosate, growers could potentially be selecting for early-emerging weeds that may be too large to control at the typical timing for these herbicides. In addition, they could be selecting for late emerging weeds that germinate after the application.

Rotate Herbicides Early in Stand Life So Glyphosate Remains Effective

Weed control during the last year of an alfalfa stand is often challenging because the stand is typically less dense and competitive and also there are fewer herbicide options from which to choose. There are significant plant-back restrictions associated with many of the soil-residual herbicides used in alfalfa, so glyphosate is a good choice for controlling weeds in the final year of RR alfalfa field. The preference to use glyphosate in the final year of an alfalfa stand underscores the importance of rotating herbicides earlier so that glyphosate will remain effective and continue to control the majority of the weeds.

Consider a Soil-Residual Herbicide for Summer Annual Weed Control

Summer annual grass weeds such as yellow and green foxtail (Setaria spp.), barnyardgrass (*Echinochloa crus-galli*), cupgrass (*Eriochloa* spp.), and jungle rice (*Echinochloa colona*), and less frequently, broadleaf weeds like pigweed (*Amaranthus* spp.) or lambsquarters (*Chenopodium album*), can be problematic in established alfalfa. These weeds emerge over an extended time period whenever soil temperatures and moisture are adequate, typically from late winter or early spring (as early as February in the Central Valley) throughout the summer. Weeds may emerge between alfalfa cuttings, so several applications may be necessary in California's Central Valley for a foliar herbicide without residual activity like glyphosate to provide season-long control.

Multiple applications of a single herbicide during a season is cited as promoting weed resistance. Therefore, growers should not rely solely on glyphosate for summer grass control for multiple seasons. It remains to be seen how many applications of glyphosate will be required for season-long summer grass control. In some of the long growing-season areas of California, as many as two to three applications per season may be needed in older, thinner stands. Rather than making multiple applications of glyphosate, a better approach may be to apply a pre-emergence soil-residual dinitroaniline herbicide like trifluralin (Treflan) or pendimethalin (Prowl), or possibly EPTC (Eptam), and follow up with glyphosate later in the season as needed for escapes. Not only is this approach more in line with management practices to avoid weed shifts and resistance, but it may be more economical as well, compared with multiple applications of glyphosate.

The practice of rotating herbicides or applying tank mixtures is recommended for both dormant applications aimed at winter annual weeds and for spring/summer applications intended to control summer annual weeds. For example, rotating to hexazinone (Velpar) for winter annual weed control for a year does nothing to prevent weed species shifts or the evolution of resistance in the summer annual weed spectrum. Herbicides for summer annual weed control should be rotated as well.

Frequency of Rotation Depends on Weed Species and Escapes

There is no definitive rule on how often herbicides should be rotated. Our suggestion to rotate or tank mix at least once in the middle years of the life of a stand (or more often for long-lived alfalfa stands) may need to be modified depending upon actual observations of evolving weed problems. The key point, which cannot be overemphasized, is the importance of diligent monitoring for weed escapes. Producers should stay alert to the appearance of weed species shifts and evolution of resistant weeds. If the relative frequency of occurrence of a weed species increases dramatically, chances are that it is tolerant to glyphosate and immediate rotation of herbicides or a tank mix is advised. If a few weeds survive among a weed species that is normally controlled easily with glyphosate, it could be an indication of weed resistance, assuming misapplication and other factors can be eliminated as possible causes. Weed resistance should be confirmed by controlled studies conducted by a weed scientist. However,

in these situations, it is imperative to prevent reproduction of a potentially resistant biotype. Treat weed escapes with an alternative herbicide or other effective control measure.

CONCLUSIONS

The Roundup Ready alfalfa production system has the potential to simplify weed management, while also improving the spectrum of weed control. However, growers should learn from the experience gained in other crops and stay alert to the occurrence of weed shifts and evolution of resistant weeds. The key is for growers to reduce selection pressure, not to rely on repeated applications of glyphosate year after year, application after application. Well-known management principles are available to manage weed shifts and weed resistance in RR alfalfa. Rotate crops, rotate herbicides, and utilize tank mixes as needed, depending on the weed species and weed escapes present. A grower should not wait for a problem to occur before he or she employs these practices; a preemptive approach is strongly encouraged.

METRIC CONVERSIONS

English	Conversion factor for English to metric	Conversion factor for metric to English	Metric
pound (lb)	0.454	2.205	kilogram (kg)
acre (ac)	0.4047	2.47	hectare (ha)
pound per acre (lb/ac)	1.12	0.89	kilogram per hectare (kg/ha)

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WARNING ON THE USE OF CHEMICALS

Pesticides are poisonous. Always read and carefully follow all precautions and safety recommendations given on the container label. Store all chemicals in their original labeled containers in a locked cabinet or shed, away from foods or feeds, and out of the reach of children, unauthorized persons, pets, and livestock.

Recommendations are based on the best information currently available, and treatments based on them should not leave residues exceeding the tolerance established for any particular chemical. Confine chemicals to the area being treated. THE GROWER IS LEGALLY RESPONSIBLE for residues on the grower's crops as well as for problems caused by drift from the grower's property to other properties or crops.

Consult your county agricultural commissioner for correct methods of disposing of leftover spray materials and empty containers. Never burn pesticide containers.

PHYTOTOXICITY: Certain chemicals may cause plant injury if used at the wrong stage of plant development or when temperatures are too high. Injury may also result from excessive amounts or the wrong formulation or from mixing incompatible materials. Inert ingredients, such as wetters, spreaders, emulsifiers, diluents, and solvents, can cause plant injury. Since formulations are often changed by manufacturers, it is possible that plant injury may occur, even though no injury was noted in previous seasons.

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Appendix E

Effects of Glyphosate-Resistant Weeds in Agricultural Systems (Appendix G from Draft EIS)

Appendix G. Effects of Glyphosate-Resisant Weeds in Agricultural Systems

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Effects of Glyphosate-Resisant Weeds in Agricultural Systems

Executive Summary

Alfalfa is grown for forage, grazing, seed production (forage and sprouts), human consumption, and honey production. The most acreage is for dry hay forage. In 2005, 22,439,000 acres of dry hay alfalfa was harvested and 204,380 (0.9%) of those acres were certified organic. In addition to mechanical and cultivation techniques, conventional farming allows the use of 16 different herbicides to control weeds in alfalfa. Organic farming does not allow synthetic pesticides or the use of crop varieties produced through genetic engineering. Glyphosate-tolerant (GT) alfalfa allows for the application of glyphosate directly onto growing plants, which provides increased options for weed control over conventional and organic systems. GT alfalfa allows for flexibility in timing of glyphosate application to control weeds. In the two years that GT alfalfa seed was on the market ~200,000 acres were planted in 1,552 counties in 48 states.

Alfalfa Growing Regions

The seven growing regions in the United States have varying optimal alfalfa varieties and farming practices, such as frequency of cutting, companion cropping, and irrigation. California, South Dakota, Idaho, Nebraska, Montana, and Wisconsin are the top six alfalfa hay producing states (in 2007). South Dakota, Montana, Wisconsin, and North Dakota, have the largest acreage of alfalfa hay. California's acreage is highly productive.

Crop Rotations

Crop rotation options may be different between conventional and GT farming systems. Many of the non-glyphosate herbicides have follow-up planting restrictions that limit crop rotation choices in conventional farming. Farmers using GT cropping systems are advised to include some years of non-GT crops in rotation, so there may be limitations in the use of other GT crops if GT alfalfa is used in a rotation plan.

Alfalfa Stand Removal

Glyphosate is the primary tool used to remove conventional alfalfa stands. Use of herbicides other than glyphosate for removal of GT alfalfa is a major difference between GT alfalfa and conventional alfalfa. Non-glyphosate herbicides and tillage are recommended for effective GT alfalfa stand removal.

Volunteer Alfalfa

Farmers are not able to use glyphosate to control volunteer GT alfalfa in other GT crops. However, 11 other herbicides and mixtures of those herbicides are available to control volunteer GT alfalfa. These are the same herbicides that are used to control non-GT alfalfa with the exception that glyphosate can be used to control non-GT alfalfa.

Weeds in Alfalfa

Weeds are controlled in conventional alfalfa with chemicals (herbicides), cultural methods (rotation, companion crops, monitoring), and mechanical methods (tillage). The cultural and mechanical methods are permitted for organic farmers. GT systems allow for the use of one additional herbicide, glyphosate. Weeds are undesirable because they compete with crops, leading to lower yields, can lower the nutritional value of crops, can be poisonous or unpalatable to livestock, can cause off flavors in milk, and can cause trouble with bailing. At least 129 different weed species are identified as minor or major problems in alfalfa. Out of 14 new glyphosate resistant weeds found since 1998, eight are known to be weeds in alfalfa. Out of at least 21 weeds that have natural resistance to glyphosate, ten are known to be a problem in alfalfa. These 18 weeds that are both resistant to glyphosate and traditionally listed as problems in alfalfa include: common ragweed, horseweed, Italian ryegrass, Johnsongrass, Palmer Amaranth, buckhorn plantain, goosegrass, junglerice, bermudagrass, burning nettle, cheeseweed, common lambsquarters, field bindweed, filaree, large crabgrass, morningglory, nutsedge, and purslane. Although the composition of weed shifts is based on the local seedbank, these 18 weeds are candidates for becoming more prevalent than glyphosate-resistant sensitive weeds in rotations that include GT alfalfa.

Glyphosate Resistant Weed Distribution

Nineteen states and over two million acres of cropland contain new glyphosate resistant weeds. The heaviest infestation is in the Southeast and Midwest. Overlap with the major alfalfa producing states in the Intermountain regions (Washington, Oregon, Idaho, Montana, Wyoming, Colorado, Utah, Nevada, and parts of California) seems to be minimal at this point. However, given that there is overlap between glyphosate resistant weed locations and alfalfa hay acreage there is potential for rapid shifts of glyphosate resistant weeds into GT alfalfa fields if GT alfalfa were to be widely adopted. California is a concern because glyphosate resistant weeds are present and alfalfa is a major crop in California.

1.0 Introduction

The scope of this report covers how glyphosate-tolerant (GT) alfalfa could impact weed dynamics in agricultural systems. Gene flow from GT alfalfa is covered in another technical report in this series (Appendix J). In this report, different types of alfalfa crops and cropping systems are described. Regional differences in alfalfa farming are summarized and discussed within the context of weed management. Glyphosate resistant weeds and the potential risks from volunteer GT alfalfa are also discussed. This report is limited to weed dynamics in agricultural systems. Potential effects of farming with GT alfalfa on ecosystems is discussed in other technical reports. This report is limited to practices involving weed management and does not include discussion of control of diseases, insects, nematodes, and vertebrate pests and management of field fertility and soil conservation.

Weed management is an important aspect of alfalfa production. Some of the negative effects of weeds include the following (Canevari et al., 2007; Canevari et al., 2006; Van Deynze et al., 2004; Loux et al., 2007; Miller et al., 2006; Orloff et al. 1997):

- Competition with weeds can reduce yield and cause thinning in the stand.
- Weeds can lower the nutritional quality of alfalfa hay because many weeds are lower in protein (50 percent less protein than alfalfa) and higher in fiber compared to alfalfa.
- Poisonous weeds containing toxic alkaloids (e.g., common groundsel, fiddleneck, yellow starthistle, and poison hemlock) can make alfalfa hay unmarketable.
- Under some conditions weeds can accumulate toxic nitrate concentrations (e.g., lambsquarters, kochia, and pigweed).
- Some weeds with a spiny texture can cause mouth and throat ulcerations in livestock (e.g., foxtail, wild barley, cheatgrass, and bristlegrass).
- Weeds that are unpalatable to livestock result in less feeding and, therefore, less productivity (either beef or milk).
- Some weeds can contribute to off flavors in milk (wild celery, Mexican tea, creeping swinegrass, and mustards).
- Weeds that contain higher moisture content than alfalfa (dandelion) can cause bail problems such as mold, off-color hay, and high bale temperatures, which are a fire hazard.

Without weeds, alfalfa can grow at a density of about 12 plants per square foot. Heavily infested stands can have less than one alfalfa plant per square foot (Canevari et al., 2007). In California, if weeds are not effectively controlled weeds can represent up to 76 percent of the first cutting yields (Gianessi et al, 2002). The limiting factor for weed control in alfalfa is that, by the time alfalfa reaches the stage of growth that is tolerant to herbicides, weeds are also beyond their susceptible stage (Gianessi et al., 2002). Glyphosate-tolerant alfalfa was developed so that the broad spectrum herbicide, glyphosate, could be applied directly to alfalfa fields to control weeds. The glyphosate-tolerant (GT) trait was introduced through genetic engineering. Although glyphosate-tolerance has arisen naturally in some plants due to decades of glyphosate use, so far, all crops with glyphosate-tolerance have had the trait introduced through genetic engineering.

1.1 Methodology

A literature search was designed to identify peer review articles and grey literature (e.g., government reports, State Agricultural Extension Office publications) on weeds in alfalfa (Appendix G-2 of this technical report). Several DIALOG databases were searched. Google, Google Scholar, Scirus, and Yahoo search engines supplemented the DIALOG search. Calculations for percentages of harvest were done with Microsoft Excel. Alfalfa harvest statistics were obtained from USDA's National Agricultural Statistics Service (http://www.nass.usda.gov/index.asp). In addition, USDA's Economics, Statistics and Market Information System (ESMIS), which is a collaborative project between Albert R. Mann Library at Cornell University and USDA, provided information on alfalfa harvesting (http://usda.mannlib.cornell.edu/MannUsda/homepage.do). USDA's Agricultural Marketing Service also provided information on harvests (http://www.ams.usda.gov). The common and scientific names for weeds (Appendix G-3 of this technical report) were found in the USDA Plants database (http://plants.usda.gov/java/invasiveOne).

2.0 Alfalfa Cropping Systems

This chapter discusses how alfalfa is used, the farming practices for growing alfalfa, and the alfalfa growing regions in the United States.

2.1 Alfalfa Uses

Alfalfa is grown for seed production, human food, honey, grazing, and forage. Forage comprises the largest acreage for alfalfa stands. In 2007, 72.5 million tons of dry hay alfalfa was produced from 21.6 million acres harvested (www.nass.usda.gov).

2.1.1 Forage

Alfalfa is considered the "Queen of Forages" because of its high nutritional content when fed to cattle and horse livestock (Putnam et al., 2001). Due to climate and other differences, farming practices differ regionally. However, some farming characteristics are shared among growing regions. Alfalfa stands have two growing phases, establishment of seedlings (first year) and established (two to eight years). Weed management differs for each phase (Orloff et al., 1997). During the seedling establishment phase, companion or nursery crops, such as oats, wheat, and barley can be used to help shelter the alfalfa seedlings, help prevent soil erosion, and suppress weeds because they germinate and grow faster than alfalfa (Canevari et al, 2007). Well established alfalfa that is not thinning has fewer issues with weeds because established alfalfa is a good competitor. Alfalfa can be harvested (mowed) every 30 to 50 days depending on growth conditions in the region, local weather patterns, and alfalfa variety. In most of the growing regions, alfalfa is only cut three to four times a year, but in the Southwestern U.S. growers can cut up to10 or 11 times per year (Putnam et al., 2001). To determine when to harvest, farmers balance yield and nutritional content. Yield increases as plants grow and peaks at 100% bloom, but nutritional content is highest in young vegetative plants and decreases until full flower. There is no optimal harvest schedule, because farmers make different decisions based on changing market demand. Farmers may choose to harvest between late bud stage and full bloom, however, alfalfa hay production experts recommend cutting alfalfa for hay at 10% bloom, as this stage provides the most valuable and nutritious forage (e.g., Sheaffer et al. 2000). . The highest quality hay (bud stage) is generally used for active dairy cows. Whereas hay that is lower in protein and higher in fiber, is fed to beef cattle, horses, heifers (too young to milk) and non-lactating dairy cows (Ball et al., no year). Alfalfa for livestock feed can be stored in a variety of forms:

- Hay - dry bailed at 18-20% moisture
- Haylage - round bale silage, baled at 50-60% moisture, wrapped in plastic
- Silage - chopped and blown into a silo or a truck

2.1.2 Grazing

Grazing is sometimes used as an alternative to harvesting alfalfa. Grazing allows for high nutritional gains per animal, but the risks include animal losses due to bloating and difficulties in alfalfa stand maintenance if continuous grazing is present. Farmers may choose grazing for dormant-season alfalfa stubble, a substitute for early or late season cutting, and rotational grazing during the growing season. It is strongly recommended that animals not graze before flowering begins. Alfalfa root carbohydrate reserves may not be sufficient if early grazing is permitted and the potential for bloat decreases with flowering (Orloff et al., 1997).

2.1.3 Seed Production (Hay and Sprouts)

Alfalfa is also consumed by humans (e.g., sprouts, dietary supplements, and herbal teas). Sprouts have been the source of several foodborne outbreaks due to bacterial contamination (FDA 1999). Epidemiological investigations suggest that seeds are the likely source in most, if not all, sprout-associated illness outbreaks. Seed grown for sprouts have more stringent restrictions for chemical applications during growing since the chemicals must be evaluated as food residues. Sources of animal waste in fields, such as grazing areas and irrigation water, must also be controlled to reduce the likelihood of pathogens from animal waste coming into to contact with seeds. For these reasons, sprout seed and hay seed are usually grown separately (FDA 1999).

FDA considers GT alfalfa not materially different from conventional alfalfa; therefore it is permitted for human consumption (FDA 2004). However, Monsanto does not allow GT alfalfa to be planted for sprouts (Hubbard 2008). If GT alfalfa was present in human food, it would not be considered adulterated and would not need to be removed from the market.

2.1.4 Honey

Alfalfa and clover are common nectar sources for honey bee hives. Although alfalfa is not specifically grown for bees, both managed and wild bee hives are often associated with alfalfa fields (Hammon et al., 2007).

2.2 Alfalfa Farming Practices

Alfalfa framing practices are broken into three categories, organic, conventional, and glyphosate-tolerant alfalfa. Only aspects of farming related to weed control are discussed. Practices for controlling disease, insects, nematodes, and vertebrate pests and management of field fertility and soil conservation are not discussed.

2.2.1 Organic Farming

For this report, organic production is only those cropping systems that fall under the USDA National Organic Program (NOP) definition of organic farming and are certified organic production systems. In organic systems, the use of synthetic pesticides, fertilizers, and genetically engineered crops is strictly limited. NOP publishes a list of approved substances for organic farming inputs (http://www.ams.usda.gov/AMSv1.0).

GT alfalfa is not approved for use in organic systems because it is genetically engineered and because glyphosate application is not permitted in organic systems.

In organic systems, where herbicides are not permitted, alfalfa is tilled and allowed to sit for seven to ten days. Two or more discing passes may be necessary if weed germination is observed. The field should also be treated with nutrients, such as compost and boron, and left for a week to check for further weed germination. Planting can occur once weed growth potential is minimized (Guerena and Sullivan 2003). Manure fertilizer should be composted to kill weed seeds (Canevari et al., 2007).

2.2.2 Conventional Farming

Conventional farming includes any farming system where synthetic pesticides or fertilizers are used. The definition of conventional farming usually includes the use of genetically engineered crops, but genetically engineered GT alfalfa is considered separately for this report (Harker et al., 2005). Conventional farming covers a broad scope of farming practices, ranging from farmers who only occasionally use synthetic pesticides to those farmers whose harvest depends on regular pesticide and fertilizer inputs. The 16 herbicides that may be used in conventional farming are summarized in table G-1 (based on OMAFRA 2008; Canevari et al., 2007; Rogan and Fitzpatrick 2004; Loux et al., 2007).

Table G-1. Herbicides Used in Conventional Alfalfa Farming

Herbicide (Brand)	Stand Stage	Weed	Notes
2,4-DB (Butyrac, Butoxone)	1-4 trifoliolate or established stands	Prickly lettuce Annual sowthistle Mustards Curly dock	• No harvesting or grazing allowed for 60 days following treatment
Benefin (Balan)	Before seeding	Annual grasses Broadleaf	• Not for use on soils high in organic matter
Bromoxynil (Buctril)	2-4 trifoliolate	Coastal fiddleneck Mustard0s Common groundsel Annual sowthistle	• Often tank mixed with other herbicides
Clethodim (Prism, Select)	2-4 trifoliolate or established stands	Summer grasses Yellow foxtail Green foxtail Barnyardgrass Bermudagrass Johnsongrass Goosegrass Volunteer cereals	• Well established perennials require multiple applications • Allow 15 days between application and grazing, feeding, or harvesting of alfalfa
Diuron (Karmex, Direx)	Established stands	Winter annuals Broadleaf Some grasses	• Persists in soil for one year, so cannot be used in last year of stand
EPTC (Eptam)	Established stands	Summer grasses Nutsedge	• Applied before germination • Controls for 30 to 45 days so repeated applications may be necessary

Hexazinone (Velpar)	6 inches of root growth in new stands or established stands	Broadleaf Grasses Common groundsel Chickweed miners Lettuce annual Bluegrass dandelion Buckhorn plantain Speedwell	• Many crops cannot be planted for 18 months without yield damage
Imazamox (Raptor)	2-4 trifoliolate or established stands	Winter annual Grasses Broadleaf	• Preharvest interval is 20 days
Imazethapyr (Pursuit)	2-4 trifoliolate or established stands	Winter annuals Mustards Shepherd's purse Creeping swinecress Chickweed	• Follow-up planting restrictions range from 4 to 40 months
Metribuzin (Sencor)	Established stands	Lamb's-quarters Wild mustard Redroot pigweed Common ragweed Shepherd's-purse Lady's-thumb Velvetleaf Jimsonweed Prostrate pigweed Russian thistle Yellow wood-sorrel Prickly mallow Chickweed Cocklebur Carpetweed Dandelion seedlings Barnyard grass Crab grass Foxtail Fall panicum Witch grass Johnson grass Cheat grass	• No grazing or harvesting allowed for 28 days following application
Norfluzaon (Solicam)	Established stands	Broadleaf Grasses Nutsedge	• Cannot be applied within 28 days of harvest • Does not control emerged weeds • 24 month rotation interval
Paraquat (Gramoxone Inteon)	3, 6, or 9 trifoliolate; established stands	Broad spectrum	• Rescue treatment when weeds form a canopy over alfalfa • No harvest or grazing until 60 days after application • Often used in the last year of the stand
Pronamide (Kerb)	First trifoliate leaf stage	Perennial grasses Quack grass Annual grasses Volunteer cereals Common chickweed	• No grazing or harvesting allowed for 120 days following application
Sethoxydim (Poast)	2-4 trifoliolate or established stands	Summer grasses Yellow foxtail Green foxtail Barnyardgrass Bermudagrass Johnsongrass Goosegrass	• Well established perennials require multiple applications
Terbacil (Sinbar)	Established stands	Barnyard grass Bluegrass Crab grass Foxtail Chickweed Cheat grass Perennial rye grass Wild barley Mustard Prickly lettuce Stinkweed Annual sow-thistle Henbit Lamb's-quarters Pigweed	• Can not plant any other crop for 2 years after Sinbar application

		Purslane Ragweed Partial control of: Quack grass Horsenettle Vetch Yellow nut sedge	
Trifluralin (Treflan/TR-10)	Established stands	Summer grasses	• Applied before germination • Rainfall or sprinkler irrigation is required within 3 days after irrigation to incorporate the herbicide • Controls dodder before germination

2.2.3 GT Farming

GT alfalfa can be integrated into conventional farming practices. Farming GT alfalfa is mostly the same as farming conventional alfalfa, with two important exceptions. Weeds can be controlled by the application of glyphosate directly on top of growing alfalfa and, when alfalfa stands reach the end of their life cycle (typically after 3-8 years depending on growing region), glyphosate cannot be used to kill the stand to prepare for another rotation (Miller et al., 2006). In GT alfalfa, herbicides other than glyphosate combined with tillage are required to obtain 100 percent removal. Several of the recommended GT alfalfa stand removal herbicides result in restrictions regarding what crops can be planted next, so careful crop rotation plans are necessary when using GT alfalfa. Stand removal is discussed in the technical report *Effects of Changes in Farming Practices on Water, Soil and Air Due to Use of Glyphosate-Tolerant Alfalfa* (appendix J).

Another important difference to some farmers is that non-GT crops cannot be used as companion crops for GT alfalfa. For farmers that plant pure alfalfa stands this difference does not matter. For farmers that traditionally use companion crops, this difference is important. Companion crops can increase overall forage yield but decrease hay quality (McCordick et al., 2008).

2.2.4 Crop Rotation in Alfalfa

For weed, insect, and disease management, it is recommended that alfalfa be used in rotation with other crops. It is also advised to rotate alfalfa because mature alfalfa produces medicarpin, which is auto toxic to seedling alfalfa (Guerena and Sullivan 2003). This autotoxicity is the primary problem for alfalfa seeded after alfalfa (Jennings, no year). Table G-2 presents rotation recommendations for control of several common alfalfa pests.

Table G-2. Recommended Rotations for Pest Reduction (Goodell 2006)

Pest	Recommended Rotation
Root knot nematode	1 year rotation with cotton
Stem nematode	3-4 year rotation with small grains, beans, cotton, corn, sorghum, lettuce, carrots, tomatoes, or forage grasses.*
Diseases: Bacterial wilt Anthracnose Spring blackstem Common leafspot Stagonospora	3-4 year rotation with small grains, beans, corn, sorghum, forage grasses.*
Winter weeds	A minimum of 1 year (preferably longer) in crops such as small grains, wheat, oats, winter forage grasses that allow the use of selective herbicides that are not registered in alfalfa.
Summer weeds	A minimum of 1 year (preferably longer) in crops such as small grains, beans, cotton, corn, sorghum, summer forage grasses that allow the use of selective herbicides that are not registered in alfalfa.
Dodder	At least 2 years with cotton or other nonhost crops such as small grains, beans, corn, sorghum, or forage grasses. Avoid rotations with crops such as tomatoes, onions, and carrots that also serve as a host for this weed.
Nutsedge	Two year rotation with corn or sorghum rotation that includes application of herbicide to control nutsedge.

* Three to four-year rotations give satisfactory results. A rotation for fewer years will provide minimal suppression.

Herbicides that can be used to remove GT alfalfa have rotation restrictions. For example, following clopyralid (Curtail® or Stinger®), pea, lentil, potato, and dry bean cannot be planted for 18 months. Picloram (Tordon®) can only be followed by grasses for the year after application. Sunflower, dry bean, and potato should not be planted for several years following picloram (Miller et al., 2006). Dicamba (Banvel®) should not be used prior to soybean and is also limited seasonally in California (Dillehay and Curran 2006). Because of these restrictions, alfalfa stand removal and rotation schedules should be closely coordinated. Non-glyphosate herbicides are available to manage alfalfa volunteers in wheat, oats, barley, sugar beet, and corn. Therefore rotations from GT alfalfa to those crops should be similar to rotations with non-GT alfalfa (Rogan and Fitzpatrick 2004).

Smother crops planted before alfalfa can suppress weeds. For example, sorghum-sudangrass hybrid or foxtail millet both suppressed weeds and enhanced subsequent alfalfa establishment (Forney et al., 1985).

No-till GT corn can be planted directly into alfalfa. In a study comparing no-till GT corn planted into cut or uncut alfalfa and various herbicide applications to control the alfalfa, corn yield was 13% higher following herbicide applications to uncut alfalfa. Application of glyphosate and dicamba at planting resulted in the greatest corn yield. Given that alfalfa is also a valuable crop, whether the corn yield gain is worth the loss of an alfalfa harvest should be weighed (Glenn and Meyers 2006).

2.3 Alfalfa Growing Regions

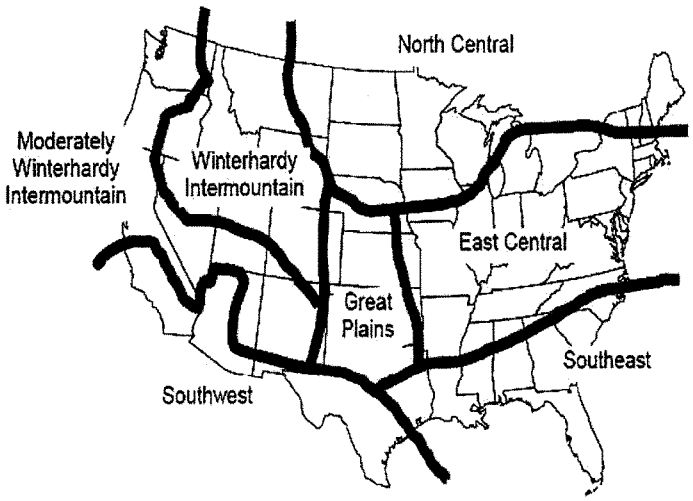


Figure G-1: Alfalfa growing regions (Rogan and Fitzpatrick 2004)

The Association of Official Seed Certifying Agencies, National Alfalfa and Miscellaneous Legumes Variety Review Board and USDA Plant Variety Protection Office recognizes seven growing regions in the United States, Moderately Winterhardy Intermountain, Winterhardy Intermountain, Southeast, Great Plains, North Central, East Central, and Southeast (figure G-1) (http://www.aosca.org/VarietyReviewBoards/Alfalfa.html). In addition, the Pacific Northwest, which includes Moderately Winterhardy Intermountain and Winterhardy Intermountain, is also sometimes recognized as a distinct growing region.

Table G-3 and table G-4 summarize the winter survival and fall dormancy ratings for alfalfa varieties. The National Alfalfa & Forage Alliance (NAFA) publishes a list of varieties and their winter survival ratings, fall dormancy ratings, and susceptibility to 17 different crop stresses (e.g., diseases, insects, grazing). The list is updated yearly and the 2007/2008 version lists 242 varieties of alfalfa (NAFA 2008). When selecting a variety, farmers consider yield, stand persistence, dormancy, pest and disease resistance, herbicide resistance, hay quality, price, seed certification, and other factors that may be specific to their farming situation (Orloff et al., 1997).

Table G-3. Winter Survival Ratings

Category	Check Variety	Score
Superior	ZG 9830	1
Very Good	5262	2
Good	WL325HQ	3
Moderate	G-2852	4
Low	Archer	5
Non Winterhardy	Cuf 101	6

Table G-4. Fall Dormancy Ratings

Check Variety	Rating
Maverick	1
Vernal	2
5246	3
Legend	4
Archer	5
ABI 700	6
Dona Ana	7
Pierce	8
CUF 101	9
UC-1887	10
UC-1465	11

1 is very dormant, 11 is extremely non-dormant

Table G-5 presents the U.S. states in order of percentage of alfalfa harvest (in 2005). For each state, the growing region, the percentage of the total national harvest of all alfalfa are presented for 2002, 2005, and 2007; and the percentage of the national organic certified harvest are presented for 2002 and 2005. In 2005, the most recent USDA organic harvest report, 22,439,000 acres of dry hay alfalfa was harvested and 204,380 (0.9 percent) of those acres were certified organic. The number of acres harvested in a state does not indicate the quantity of the harvest. For example, as shown in table G-5, because of the growing season length, California ranks top in production (in 2007, ~11 percent of the national harvest and ~7 million pounds) and South Dakota ranks second (in 2007, ~6.8 percent of the national harvest and ~4 million pounds) even though South Dakota has ~2 million acres and California has less than 1 million acres of alfalfa.In addition, even though the Northeastern states rank low in the percentage of acres and quantity of harvest, alfalfa is the number one crop for several of those states (NAFA 2007).

Table G-5. Alfalfa Growing Regions and Percentage of Dry Hay Harvest by State

State	Growing Region	Percent of harvest acres			Percent of organic harvest	
		2002	2005	2007	2002	2005
South Dakota	North Central	10.57	10.70	9.86	8.58	6.82
Montana	Winter Hardy Intermountain	6.76	7.80	9.23	3.66	2.60
North Dakota	North Central	6.13	7.35	7.20	11.22	10.09
Wisconsin	North Central	7.32	6.91	7.50	16.34	14.38
Minnesota	North Central	5.59	6.02	4.67	6.40	10.44
Iowa	North Central	5.16	5.57	4.10	6.11	4.50
Nebraska	North Central	5.92	5.57	5.36	2.71	4.01
Idaho	PNW-Intermountain	4.57	5.08	5.12	24.69	24.22
California	Moderate Winter Hardy Intermountain/ Southwest	5.19	4.63	4.88	2.92	6.48
Michigan	East Central	3.56	4.01	3.45	2.07	0.35
Kansas	Great Plains	4.14	3.79	3.92	1.40	0.32
Colorado	Winter Hardy Intermountain	3.40	3.57	4.25	3.45	4.38
Wyoming	Winter Hardy Intermountain	2.16	2.67	3.33	0.19	0.84
Utah	Moderate Winter Hardy Intermountain	2.48	2.41	2.71	0.60	0.45
Ohio	East Central	2.71	2.27	2.16	1.89	0.50
Pennsylvania	East Central	2.96	2.27	2.35	0.96	0.60
Missouri	East Central	1.77	2.01	1.46	0.23	0.58
New York	East Central	2.90	2.01	2.22	1.34	0.16
Washington	PNW-Intermountain	2.37	2.01	2.22	1.19	0.56
Illinois	East Central	1.84	1.78	1.59	0.80	1.22
Oregon	PNW-Intermountain	2.15	1.78	2.12	0.42	3.23
Indiana	East Central	1.41	1.52	1.19	0.03	0.29
Oklahoma	Great Plains	1.54	1.43	1.65	0.00	0.04
Kentucky	East Central	1.37	1.16	1.33	0.00	0.01
Nevada	Moderate Winter Hardy Intermountain	1.34	1.16	1.35	1.25	1.47
Arizona	Moderate Winter Hardy Intermountain/ Southwest	1.03	1.16	1.27	0.91	0.24
New Mexico	Moderate Winter Hardy Intermountain	0.83	1.07	1.17	0.14	0.33
Texas	Great Plains/ Southwest/ Southeast	0.72	0.67	0.76	0.18	0.55
Virginia	East Central	0.62	0.49	0.44	0.31	0.14
Vermont	East Central	0.20	0.20	0.16	0.00	0.00
Maryland	East Central	0.25	0.18	0.20	0.00	0.01
Tennessee	East Central	0.13	0.16	0.10	0.00	0.00
West Virginia	East Central	0.23	0.16	0.14	0.00	0.00
New Jersey	East Central	0.12	0.11	0.10	0.00	0.00
Arkansas	East Central	0.07	0.09	0.06	0.00	0.00
Massachusetts	East Central	0.07	0.06	0.05	0.00	0.00

State	Growing Region	Percent of harvest acres			Percent of organic harvest	
		2002	2005	2007	2002	2005
Maine	North Central	0.06	0.05	0.05	0.00	0.17
North Carolina	Southeast	0.10	0.05	0.05	0.00	0.00
Connecticut	East Central	0.04	0.04	0.04	0.00	0.05
New Hampshire	East Central	0.04	0.04	0.03	0.00	0.00
Delaware	East Central	ND	0.02	0.02	0.00	0.00
Rhode Island	East Central	0.01	0.01	0.01	0.00	0.00
Florida	Southeast	0.02	0.00	0.03	0.00	0.00
Georgia	Southeast	0.01	0.00	0.01	0.00	0.00
Louisiana	Southeast	0.03	0.00	0.01	0.00	0.00
Mississippi	Southeast	ND	ND	0.02	ND	ND
South Carolina	Southeast	0.01	0.00	0.02	0.00	0.00
Alabama	Southeast	0.04	ND	0.04	0.00	ND
Alaska		0.00	ND	0	0.00	ND
Hawaii		ND	0.00	0.00	0.00	0.00

ND = no data provided by USDA

Other differences in alfalfa farming are revealed by examining the number of farms that grow alfalfa and the number of farms that irrigate. Comparison of California and Wisconsin (table G-6) shows that in California ~97 percent of the farms irrigate, whereas in Wisconsin only 0.5 percent of the farms irrigate. In addition, the average farm size in California is much larger than in Wisconsin. It should be noted that the average farm size calculation is a bit misleading because in California mainly two farm sizes exist, small and very large (4,000 acres). In general, because farm size does not fit a normal distribution, the average farm size does not give a full picture of farm sizes. However average farm size does relay the general trend of farm size in a state. Like any census, these data may not include all alfalfa farms.

Table G-6. Alfalfa Dry Hay Harvest 2007 U.S. Agricultural Census

State	Number of Farms	Acres Harvested	Quantity (pounds) Harvested	Farms Irrigated	Acres Irrigated	% of Acres	% of Pounds	Avg. Acres per Farm
United States	290,726	20,244,497	65,349,074	56,390	6,556,652	100.0	100.0	70
California	3,587	986,982	7,057,014	3,488	963,086	4.9	10.8	275
South Dakota	12,653	1,996,599	4,414,338	716	75,913	9.9	6.8	158
Idaho	8,817	1,037,520	4,254,543	7,605	861,092	5.1	6.5	118
Nebraska	14,820	1,085,921	3,955,881	4,405	389,516	5.4	6.1	73
Montana	9,711	1,868,756	3,936,445	5,444	703,960	9.2	6.0	192
Wisconsin	30,810	1,517,522	3,673,619	171	8,809	7.5	5.6	49
North Dakota	8,985	1,457,604	3,072,682	240	21,773	7.2	4.7	162

Iowa	22,040	830,440	3,054,729	62	1,198	4.1	4.7	38
Kansas	9,643	793,140	2,986,134	1,115	207,455	3.9	4.6	82
Colorado	8,648	861,053	2,887,865	7,347	707,234	4.3	4.4	100
Minnesota	20,398	944,775	2,671,173	384	15,603	4.7	4.1	46
Washington	4,294	448,588	2,192,001	2,822	334,005	2.2	3.4	104
Utah	7,780	548,570	2,172,218	7,413	507,798	2.7	3.3	71
Arizona	943	257,407	1,968,043	920	257,263	1.3	3.0	273
Oregon	3,569	428,812	1,777,894	3,043	380,679	2.1	2.7	120
Michigan	16,431	698,595	1,707,036	291	8,080	3.5	2.6	43
Wyoming	4,007	674,284	1,696,438	3,357	471,126	3.3	2.6	168
Pennsylvania	14,402	475,873	1,357,225	109	462	2.4	2.1	33
Ohio	15,354	437,658	1,256,174	17	536	2.2	1.9	29
Nevada	1,128	274,004	1,217,586	1,128	274,004	1.4	1.9	243
New Mexico	4,272	236,103	1,176,242	4,091	222,018	1.2	1.8	55
Illinois	12,913	322,339	1,138,512	47	906	1.6	1.7	25
Oklahoma	3,781	334,990	1,131,938	294	33,000	1.7	1.7	89
New York	7,707	450,144	1,119,421	31	901	2.2	1.7	58
Missouri	8,229	295,021	782,847	63	1823	1.5	1.2	36
Texas	2,391	153,763	721,303	1,154	98,831	0.8	1.1	64
Indiana	10,775	241,129	665,767	139	2,185	1.2	1.0	22
Kentucky	10,538	269,610	524,565	109	1,210	1.3	0.8	26
Virginia	3,063	89,213	233,807	76	679	0.4	0.4	29
Maryland	1,429	40,576	120,402	49	712	0.2	0.2	28
Vermont	571	31,769	68,624	2	(D)	0.2	0.1	56
West Virginia	1,185	28,465	62,484	5	(D)	0.1	0.1	24
New Jersey	728	20,310	51,483	39	799	0.1	0.1	28
Tennessee	1,655	20,074	45,819	28	(D)	0.1	0.1	12
Arkansas	278	11,732	28,647	15	932	0.1	0.0	42
Maine	246	10,089	23,876	0	0	0.0	0.0	41
Massachusetts	406	9,921	22,537	1	(D)	0.0	0.0	24

Connecticut	349	8,343	18,441	0	0	0.0	0.0	24
Alabama	340	7,526	16,944	13	91	0.0	0.0	22
North Carolina	758	10,322	16,755	67	360	0.1	0.0	14
Florida	141	6,951	14,993	13	1,071	0.0	0.0	49
Delaware	177	3,687	13,530	22	421	0.0	0.0	21
New Hampshire	218	5,373	13,475	5	(D)	0.0	0.0	25
South Carolina	143	4,070	8,860	20	274	0.0	0.0	28
Mississippi	159	3,931	7,113	4	35	0.0	0.0	25
Georgia	134	1,655	4,810	18	243	0.0	0.0	12
Louisiana	52	2,164	4,768	2	(D)	0.0	0.0	42
Rhode Island	63	1,035	1,806	1	(D)	0.0	0.0	16
Hawaii	5	89	267	5	89	0.0	0.0	18

D = data withheld to protect identify of individual farms

2.4 Summary of Findings

Alfalfa is grown for forage, grazing, seed production (forage and sprouts), human consumption, and honey production. The most acreage is for dry hay forage. Alfalfa is currently grown through conventional farming practices, organic farming, and in glyphosate-tolerant systems. In addition to mechanical and cultivation techniques, conventional farming allows the use of 16 different herbicides to control weeds in alfalfa. Organic farming does not allow synthetic pesticides or the use of crop varieties produced through genetic engineering. GT alfalfa allows for the application of glyphosate directly onto growing plants, which provides increased options for weed control over conventional and organic systems. In 2005, 22,439,000 acres of dry hay alfalfa was harvested and 204,380 of those acres were certified organic.

Crop rotation options may be different between conventional and GT systems. Many of the non-glyphosate herbicides have follow-up planting restrictions that limit crop rotation choices in conventional farming. Farmers using GT cropping systems are advised to include some years of non-GT crops in rotation, so there may be limitations in the use of other GT crops if GT alfalfa is used in a rotation plan.

The seven growing regions in the United States have varying optimal alfalfa varieties and farming practices, such as frequency of cutting, companion cropping, and irrigation. California, South Dakota, Idaho, Nebraska, Montana, and Wisconsin are the top six alfalfa hay producing states (in 2007). South Dakota, Montana, Wisconsin, and North Dakota, have the largest acreage of alfalfa hay. California's acreage is highly productive.

3.0 Glyphosate-Tolerant Alfalfa (Roundup Ready®)

Glyphosate-tolerant (GT)[23] alfalfa was deregulated in 2005 and by 2006, ~80,000 ha (~200,000 acres) were planted in the United States (Beckie and Owen 2007).[24] USDA APHIS lists all the counties in the United States where GT alfalfa has been planted (http://www.aosca.org/VarietyReviewBoards Alfalfa.html). GT alfalfa has been planted in 1,552 counties and 48 states. Alaska and Hawaii do not have GT alfalfa. In March of 2007 USDA published notice in the Federal Register that GT alfalfa is a regulated article and GT alfalfa seed sales and plantings were halted. GT alfalfa planted in the 2005 and 2006 growing seasons is still permitted to be harvested, but has court ordered stewardship practices to minimize risk of co-mingling GT and non-GT alfalfa (Hubbard 2008).

3.1 Using GT Alfalfa

Van Deynze et al., (2004) reported that in field trials when Roundup® (glyphosate) was applied during alfalfa stand establishment at the 3 to 4 trifoliolate stage, weeds were controlled and usually no second application was needed. Early applications allowed for late germination of weeds and later applications allowed weeds to compete with alfalfa. For example in the intermountain region applications at the unifoliolate to first trifoliolate stage resulted in invasion by prickly lettuces and henbit and required a second application. In the Southwest annual bluegrass and canarygrass germinated in early December and required a second application of glyphosate for control. The effectiveness of the first application during stand establishment is a function of which weed species are present and their germination period as well as how soon after application the alfalfa canopy covers the soil surface. In California there is period of time in the winter when alfalfa stands are dormant and rain causes winter weeds to germinate.

Recommended application of glyphosate to GT alfalfa is 0.75 to 1.5 pounds acid equivalent per acre (22 to 44 fluid ounces Roundup Weathermax 4.5S® per acre) at the three to five trifoliolate stage during stand establishment and up to five days before harvest in established stands (Dillehay and Curran, 2006). The maximum labeled rate for a single use of glyphosate on GT alfalfa is 1.55 pounds glyphosate acid equivalent per acre.

Alfalfa is polyploid (tetraploid), so small percentages (three to seven percent) of the seedlings do not have the GT trait. This is similar for other genetic traits. If glyphosate is sprayed early enough, plants containing the GT trait will fill in gaps left by dead weeds and non-GT alfalfa that was killed (Van Deynze et al., 2004). Up to six percent injury was observed after the first glyphosate application in a new stand, but was gone by the time of first harvest (McCordick et al., 2008). In GT alfalfa, crop injury from glyphosate application is much less than for other herbicides (Canevari et al, 2007).

GT alfalfa is an option for weed control; however it may not be appropriate in the following situations (Dillehay and Curran, 2006):

[23] "Resistance' and" tolerance" are usually synonyms and are often used interchangeably. In this report "tolerance" is used to indicate crop varieties that are intentionally engineered to withstand glyphosate application. "Resistance" is used to indicate weeds and weed biotypes that can withstand glyphosate application.
[24] 2.471 acres = 1 ha = 104 m²

- Alfalfa-grass mixtures and alfalfa seeded with companion/nursery crops
- Fields that have a history of low weed populations
- Fields that are rotated between alfalfa and other GT crop varieties (e.g. Roundup Ready® soybean)

McCordick et al. (2008) tested GT alfalfa in 2004 and 2005 growing seasons in field studies in Michigan. Two seeding regimes were used, clear seeded (only alfalfa seed) and oat companion crop. In both of these seeding regimes glyphosate, imazamox, and untreated conditions were tested. For the oat companion crop stands, clethodim was added to the imazamox treatment to increase control of oat. In the first year (stand establishment), temporary stunting was observed with glyphosate treatment, but it did not affect yield or stand density. Clear seeded alfalfa treated with glyphosate yielded the highest alfalfa dry matter in both years, even though combined forage yield was higher in the oat companion crop. When no herbicide was applied the oat companion crop had lower weed biomass than clear seeded alfalfa.

3.1.1 Stand Establishment

Forage alfalfa is planted in the spring and in the early fall in the Southwest and western regions. Currently trifluralin, EPTC, imazethapyr, imazamox, sethoxydim, clethodim, and bromoxynil herbicides are sometimes used during spring stand establishment and could be replaced with glyphosate if GT alfalfa is used. Use of GT alfalfa also allows weed control during late-summer and fall establishment (Rogan and Fitzpatrick 2004).

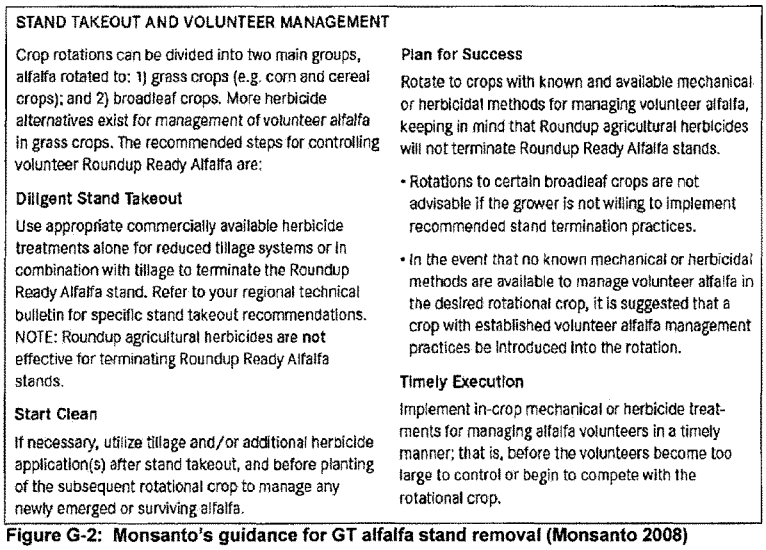
3.1.2 Stand Removal

One of the major differences between conventional alfalfa and GT alfalfa occurs during stand removal. Whereas glyphosate is often used to kill old stands of conventional alfalfa for crop rotations, GT alfalfa has to be removed through other mechanisms. Application of an herbicide (e.g., 2,4-D, dicamba (Banvel®), and clopyralid (Stinger®)) and tillage is effective. In no-till systems 2,4-D and dicamba can be applied together. However dicamba cannot be used before planting soybean (Dillehay and Curran, 2006).

Renz 2007 reported that dicamba and 2,4-D (WeedMaster®) applied at 2 pt/A achieved zero resprouting of alfalfa in the spring following herbicide application. Lower concentrations of WeedMaster resulted in 0.3 to 2.5 percent resprouting. The other herbicides applications (dicamba or 2,4-D only) resulted in 0.5 to 26.5 percent resprouting. In another study, picloram and 2,4-D was more effective than dicamba and 2,4-D (Miller et al., 2006). Combined with plowing, clopyralid, clopyralid plus 2,4-D, dicamba plus 2,4-D, picloram, and picloram plus 2,4-D all controlled alfalfa 100 percent. Plowing alone provided 75 percent control (Miller et al., 2006).

Potential effects of changes in tillage practices due to the use of GT alfalfa are discussed in the technical report *Effects of Changes in Farming Practices on Water, Soil and Air Due to Use of Glyphosate-Tolerant Alfalfa* (appendix K).

Figure G-2 shows Monsanto's guidance for GT alfalfa stand removal (Monsanto 2008).



STAND TAKEOUT AND VOLUNTEER MANAGEMENT

Crop rotations can be divided into two main groups, alfalfa rotated to: 1) grass crops (e.g. corn and cereal crops); and 2) broadleaf crops. More herbicide alternatives exist for management of volunteer alfalfa in grass crops. The recommended steps for controlling volunteer Roundup Ready Alfalfa are:

Diligent Stand Takeout

Use appropriate commercially available herbicide treatments alone for reduced tillage systems or in combination with tillage to terminate the Roundup Ready Alfalfa stand. Refer to your regional technical bulletin for specific stand takeout recommendations. NOTE: Roundup agricultural herbicides are **not** effective for terminating Roundup Ready Alfalfa stands.

Start Clean

If necessary, utilize tillage and/or additional herbicide application(s) after stand takeout, and before planting of the subsequent rotational crop to manage any newly emerged or surviving alfalfa.

Plan for Success

Rotate to crops with known and available mechanical or herbicidal methods for managing volunteer alfalfa, keeping in mind that Roundup agricultural herbicides will not terminate Roundup Ready Alfalfa stands.

- Rotations to certain broadleaf crops are not advisable if the grower is not willing to implement recommended stand termination practices.
- In the event that no known mechanical or herbicidal methods are available to manage volunteer alfalfa in the desired rotational crop, it is suggested that a crop with established volunteer alfalfa management practices be introduced into the rotation.

Timely Execution

Implement in-crop mechanical or herbicide treatments for managing alfalfa volunteers in a timely manner; that is, before the volunteers become too large to control or begin to compete with the rotational crop.

Figure G-2: Monsanto's guidance for GT alfalfa stand removal (Monsanto 2008)

3.2 Volunteer GT Alfalfa

Crop rotation is the practice of alternating crop species in the same field in different years. Crops are considered volunteer when they grow in a field during a year when they have not been planted intentionally. Volunteer crops are weeds because they compete with the current crop for resources and they may harbor insect and disease pests. For example, volunteer GT cotton in GT soybean can harbor boll weevil. Boll weevil is a serious cotton pest and is monitored aggressively in cotton for eradication. However boll weevil is not monitored in soybean (York, et al., 2004).

Volunteer GT crops have to be controlled through the use of other herbicides. For example GT wheat and canola is best controlled through paraquat and diuron (Rainbolt et al., 2004). Volunteer GT canola needs to be controlled before replanting canola because cultivars with different resistance genes can cross and result in multiple herbicide resistance (Rainbolt et al., 2004).

Herbicides that are used to control alfalfa, including GT alfalfa include (Rogan and Fitzpatrick 2004; Renz 2007; Dillehay and Curran, 2006; Miller et al., 2006):

- 2,4-D
- Clopyralid
- Dicamba
- Dicamba and diflufenzopyr
- Glufosinate
- Primsulfuron-methyl

- Mixtures of dicamba, 2,4-D, and clopyralid
- Picloram
- Picloram and 2,4-D
- Halsulfuron and dicamba
- Acetochlor
- Acetochlor and atrizine
- Acetochlor and atrizine and dicamba
- Atrizine and dicamba
- Clopyralid and flumetsulam

Monsanto demonstrated in their Deregulation Petition that the last five herbicides and mixes on the above list can control volunteer GT alfalfa in corn (Rogan and Fitzpatrick 2004). Clopyralid is effective at controlling volunteer alfalfa in broccoli (Tickes 2002). Clopyralid or 2,4-D provide control of volunteer alfalfa in 33 different crops. Exceptions include potatoes and popcorn (Rogan and Fitzpatrick 2004).

Feral alfalfa (alfalfa not in fields) is discussed in more depth in the technical report *Effects of Glyphosate-tolerant Weeds in Non-agricultural Ecosystems* (appendix H).

3.3 Summary of Findings

GT alfalfa allows for flexibility in timing of glyphosate application to control weeds. In the two years that GT alfalfa seed was on the market ~200,000 acres were planted in 1,552 counties in 48 states.

Glyphosate is the primary tool used to remove conventional alfalfa stands. Use of herbicides other than glyphosate for removal of GT alfalfa is a major difference between GT alfalfa and conventional alfalfa. Non-glyphosate herbicides and tillage are recommended for effective GT alfalfa stand removal.

Farmers are not able to use glyphosate to control volunteer GT alfalfa in other GT crops. However, eleven other herbicides and mixtures of those herbicides are available to control volunteer GT alfalfa. These are the same herbicides that are used to control non-GT alfalfa with the exception that glyphosate can be used to control non-GT alfalfa.

4.0 Weeds in Alfalfa

Although weeds can be a problem in alfalfa, once alfalfa is established, it acts as a suppressor of weeds and is commonly used in rotations for weed reduction. For example, prior rotation in alfalfa can reduce weed densities in sunflower to the same level as herbicide treatment and alfalfa in corn rotations also benefited corn yield and suppressed weeds (Clay and Aguilar 1998). Fields with a history of perennial weed infestation are not well suited for alfalfa (Canevari et al, 2007).

Wilson (1981) tested seven herbicides on dormant alfalfa in Nebraska and found good weed control that resulted in increased protein and total digestible nutrients (except for hexazinone application) compared to untreated control plots. Weeds that were successfully controlled included kochia, downy brome, tansymustard, Russian thistle, and prickly lettuce. Out of 48 weeds in alfalfa listed by the University of California Pest Management Guidelines, five weeds are not controlled by glyphosate: green foxtail, filed bindweed, yellow nutsedge, buckhorn plantain, and burning nettle. There was no data on pepperweeds. Three weeds stand out (field bindweed, yellow nutsedge, and buckhorn plantain) because they are not controlled well by glyphosate or any of the other 16 herbicides evaluated (table VII-3 in Rogan and Fitzpatrick 2004).

A list of 129 weeds that are known to infest alfalfa are in Appendix G-3 of this technical report, including the U.S. region where they are most prevalent as well as their scientific and common names.

General rules for managing weeds at establishment or in the seedling year include (Loux et al., 2007):

- Weeds that emerge with the crop are generally more destructive.
- Maintain the forage relatively weed-free for the first 60 days.
- Weeds that emerge beyond 60 days will not influence that year's forage yield.
- Later-emerging weeds may still influence forage quality.
- Winter annual weed competition in early spring is most damaging to forages.
- Broadleaved weeds are generally more competitive against legumes than grassy weeds.

4.1 Glyphosate Resistance in Weeds

Herbicide resistance can be defined as the inherited ability of a weed population to survive and reproduce following a herbicide application that is normally lethal to the vast majority of individuals of that species (lethal to the wild type) (Puricelli and Tuesca, 2005; Stoltenberg and Jeschke, no year). Farmers are concerned about glyphosate-tolerant weeds (Johnson and Gibson 2006). Figure G-3 represents the different weed populations in alfalfa. Since 1998, 14 new glyphosate resistant weeds have been found globally. Nine of these have glyphosate resistant biotypes in the United States. Eight of the new glyphosate resistant weeds known globally are also known to be weeds in alfalfa stands (see Appendix G-3 in this technical report for list of weeds in alfalfa). At least 21 weeds that have natural resistance to glyphosate exist. Ten of these naturally glyphosate resistant weeds are known to be a problem in alfalfa. Table G-7 lists

the weeds known to be glyphosate resistant in general or have glyphosate resistant biotypes. Figure G-4 summarizes the results of a recent farmer survey regarding their satisfaction with GT alfalfa and which weeds were controlled.

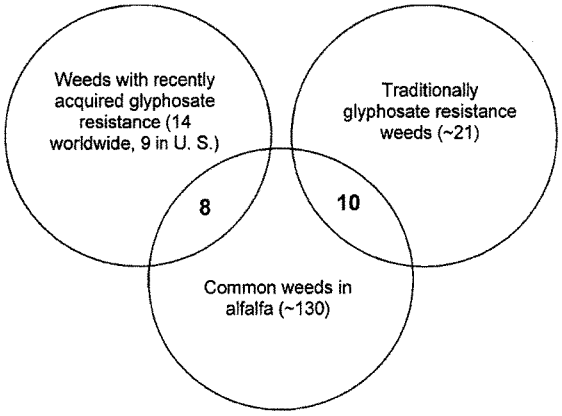


Figure G-7: Weeds in alfalfa

Table G-7. Glyphosate-resistant weeds

Common Name	Scientific Name	Resistant Biotype Reported in U.S.	Identified Problem in Alfalfa (Appendix G-3)	Listed on Roundup® Label	Source
Recently Evolved or Selected Resistant Biotypes					
Common Ragweed	*Ambrosia artemisiifolia*	Yes	Yes	Yes (with resistant biotype note)	Heap et al., 2008
Common Waterhemp	*Amaranthus rudis* and *Amaranthus tuberculatus*	Yes	No	Yes (with resistant biotype note)	Heap et al., 2008; Nandula et al., 2005
Giant Ragweed	*Ambrosia trifida*	Yes	No	Yes (with resistant biotype note)	Heap et al., 2008
Hairy Fleabane	*Conyza bonariensis*	Yes	No	Yes	Heap et al., 2008; Nandula et al., 2005
Horseweed	*Conyza canadensis*	Yes	Yes	Yes (with resistant biotype note)	Heap et al., 2008; Nandula et al., 2005

Italian Ryegrass	*Lolium multiflorum*	Yes	Yes	Yes (with resistant biotype note)	Heap et al., 2008; Nandula et al., 2005
Johnsongrass	*Sorghum halepense*	Yes	Yes	Yes (mixture also recommended)	Heap et al., 2008
Palmer Amaranth	*Amaranthus palmeri*	Yes	Yes	Yes (with resistant biotype note)	Heap et al., 2008
Rigid Ryegrass	*Lolium rigidum*	Yes	No	Yes (with resistant biotype note)	Heap et al., 2008; Nandula et al., 2005
Buckhorn Plantain*	*Plantago lanceolata*	No	Yes	No	Heap et al., 2008
Goosegrass	*Eleusine indica*	No	Yes	Yes	Heap et al., 2008; Nandula et al., 2005
Junglerice	*Echinochloa colona*	No	Yes	Yes (mixture also recommended)	Heap et al., 2008
Sourgrass	*Digitaria insularis*	No	No	No	Heap et al., 2008
Wild Poinsettia	*Euphorbia heterophylla*	No	No	No	Heap et al., 2008

Historically Naturally Resistant				
Asiatic dayflower	*Commelina communis*	No	No	Nandula et al., 2005
Birdsfoot trefoil	*Lotus corniculatus*	No	No	Nandula et al., 2005
Bermudagrass	*Cynodon dactylon*	Yes	Yes (partial control notes)	Cerdeira and Duke 2006
Burning nettle	*Urtica uren*	Yes	No (mixture recommended)	Van Deynze et al., 2004; Canevari et al., 2004
Cheeseweed	*Malva parviflora*	Yes	No (mixture recommended)	Van Deynze et al., 2004
Chinese foldwig	*Dicliptera chinensis*	No	No	Nandula et al., 2005
Common lambsquarters	*Chenopodium album*	Yes	Yes (mixture also recommended)	Nandula et al., 2005

Field bindweed*	*Convolvulus arvensis*	Yes	No (mixture recommended)	Nandula et al., 2005
Filaree	*Erodium* spp.	Yes	Yes (mixture also recommended)	Van Deynze et al., 2004
Florida pellitory	*Parietara debilis*	No	No	Cerdeira and Duke 2006
Hemp sesbania	*Sesbania exalta*	No	Yes	Cerdeira and Duke 2006
Large crabgrass	*Digitaria sanguinalis*	Yes	Yes (mixture also recommended)	Cerdeira and Duke 2006
Morning glory	*Ipomoea purpurea*	Yes	Yes (mixture also recommended)	Hilgenfeld et al. (2004; Cerdeira and Duke 2006
Nutsedge*	*Cyperus* spp.	Yes	Yes	Cerdeira and Duke 2006
Oval-leaf false buttonweed	*Spermacoce latifolia*	No	No	Cerdeira and Duke 2006
pillpod sandmat	*Chamaesyce hirta*	No	No	Cerdeira and Duke 2006
Purslane	*Portulaca oleracea*	Yes	Yes (mixture also recommended)	Van Deynze et al., 2004
Tropical Mexican clover	*Richardia brasiliensis*	No	No	Cerdeira and Duke 2006
Tropical spiderwort	*Commelina benghalensis*	No	No	Nandula et al., 2005
Velvet leaf	*Abutilon theophrasti*	No	Yes (mixture also recommended)	Nandula et al., 2005
Waterhemp	*Amarathus rudis and A. tuberculatus*	No	Yes (with resistant biotype note)	Cerdeira and Duke 2006

Cline 2004 reports that fleabane and henbit are also difficult to control with glyphosate. * These 3 weeds are not fully controlled by any of the 16 herbicides listed in the University of California Pest Management Guidelines (Rogan and Fitzpatrick 2004).

Survey of GT Alfalfa Farmers

Canevari (2007) reported survey results from interviews with alfalfa growers and industry representatives from California, Idaho, Nevada, Arizona, Washington, and New Mexico (43 respondents). The major weeds in alfalfa that were controlled by using a GT alfalfa system are listed below. Weeds that were cited as causing problems in alfalfa but were not mentioned by farmers as being controlled by glyphosate are highlighted in grey. A more comprehensive list of weeds in alfalfa is in appendix B.

Of the 24 growers surveyed all were satisfied with GT alfalfa. Advantages included less herbicide needed, yield increase, control of volunteer crops, excellent weed control, hay quality increase, better stand and water efficiency. Farmer concerns were that the seed is no longer available, the need for bale identification due to court order, and reluctance of the horse market. For the pest consultants, dealers, and researchers, concerns included export concerns, seed costs, weed resistance, weed shifts, market acceptance.

Bindweed	Dandelion	Knapweed	Morningglory
Bur clover	Dodder	Knotweed	Nutsedge
Canada thistle	Fiddleneck	Kochia	Pepperweed
Cocklebur	Foxtail	London rocket	Plantain
Common groundsel	Hoary cress	Lovegrass	Pigweed
Curly dock	Johnson grass	Mexican tea	Quackgrass
			Water grass

Figure G-4: Survey of GT alfalfa farmers

The 18 weed species (table G-7) that are both resistant to glyphosate and traditionally present problems in alfalfa likely pose the greatest threat for weed shifts in a GT cropping system. Eight weeds with newly identified resistance and ten weeds known to have some natural resistance to glyphosate are briefly described below.

4.1.1 New Glyphosate Resistant Weeds

Glyphosate resistant biotypes have recently been identified for the following eight weeds that are also common in alfalfa: common ragweed, horseweed, Italian ryegrass, Johnsongrass, Palmer Amaranth, buckhorn plantain, goosegrass, and junglerice. Each is briefly discussed below.

Common ragweed (*Ambrosia artemisiifolia*) germinates in May and early June, flowers in August to September, and sets seed in September. Each plant can release more than 30,000, three mm-long seeds, which can remain viable for more than 39 years buried. Seeds are dispersed by water and animals and can be blown across crusted snow in the winter. Common ragweed can thrive in soil containing high amounts of clay, gravel, or sand. It is found in cropland, abandoned fields, vacant lots, fence rows, waste areas, and along roadsides and railroads. Because it can accumulate large quantities of trace metals, it is very competitive and can cause nutritional deficiencies in crops. Not only does it taste bitter to livestock but it also causes nausea and mouth sores in livestock. It is very difficult to control as it can tolerate mowing, trampling, and grazing (Lanini, no year a). Common ragweed has a biotype that has multiple herbicide resistance to acetolactate synthase (ALS) inhibitors and PPO inhibitors (Heap et al., 2008).

Horseweed (*Conyza canadensis*) is a summer or winter annual that grows 1.5 to 6 feet tall (Loux et al., 2006). It produces a large number of seeds (200,000 per plant) that are wind-

dispersed. Seed dispersal in a corn field ranged from 12,500 seeds per square yard at 20 feet from the seed source, to more than 125 seeds per square yard at 400 feet from the seed source (Loux et al., 2006). Seeds can disperse a quarter mile when winds are only 10 miles per hour (Barnes et al., 2003). Seeds are able to germinate in no-till fields (undisturbed soil, includes non-crop sites) and tilled fields. Outcrossing among horseweed occurs at 1.2 to 14.5 percent which facilitates the spread of resistance traits (Stoltenberg and Jeschke, no year; Nandula et al., 2005; Loux et al., 2006). The known cases of glyphosate-resistant horseweed are characterized by frequent use of glyphosate, little or no use of alternative herbicides that control horseweed, and long-term no-tillage crop production practices (Loux et al., 2006). In addition to direct competition for light, water, and nutrients, horseweed can host the tarnished plant bug, an alfalfa pest, and the viral disease aster yellows, which is transmitted by aster leafhoppers to a wide variety of plants (Loux et al., 2006). Horseweed contains volatile oils, tannic acid and gallic acid that may cause mucosal and skin irritation in livestock (especially horses) and humans (Steckel, no year a). There are horseweed biotypes that are also resistant to ALS inhibitors. Several herbicides are effective at the rosette stage, but once horseweed is over six inches tall a three-way mixture of glyphosate, plus 2,4-D ester, plus chlorimuron or cloransulam, is recommended. Biotypes that are resistance to glyphosate and/or ALS inhibitors cannot be effectively controlled (Loux et al., 2006). In Ohio, a biotype that is resistant to both ALS inhibitors and glyphosate and a biotype in Michigan that is resistant to photosystem II inhibitors and ureas and amides have been identified (Heap et al., 2008). Over 500,000 acres in the Midwest are reported to be infested with glyphosate-resistant horseweed (Cline 2004). Others estimate that over two million acres in the U.S. are infested (Heap et al., 2008).

Italian Ryegrass (*Lolium multiflorum*) is an annual grass and is related to perennial ryegrass (*Lolium perenne*). Italian ryegrass can be intentionally cultivated with alfalfa as a companion crop and is good for grazing, hay, and silage (Hall 1992). However in cool, wet environments, it may outcompete alfalfa and, in very dry situations, it might not provide adequate ground cover (Schneider and Undersander 2008). Italian ryegrass is a weed in wheat because it stays green longer than wheat and causes cut wheat to heat and spoil (Peeper 2000). There are biotypes that exhibit multiple herbicide resistance to acetyl-CoA carboxylase (ACCase) inhibitors, ALS inhibitors, and Chloroacetamides (Heap et al., 2008). At least 5,000 acres in CA are reported to be infested with glyphosate resistant ryegrass (Cline 2004).

Johnsongrass (*Sorghum halapense*) is one of the ten most noxious weeds in the world. It is a fast-growing competitive perennial grass. Established Johnsongrass can be seven to nine feet tall and releases chemicals that inhibit surrounding plant growth. A plant produces 100 to 400 seeds that withstand silage and passage through livestock digestive systems. Seeds can germinate from 6 inches deep and are viable for three years. Stresses that interrupt normal growth, such as freezing, cutting, wilting, trampling, and herbicide exposure, can cause the release of toxic amounts of hydrocyanic acid which are poisonous to livestock. Johnsongrass is thought to be introduced from Egypt sometime after the Revolutionary War and was previously grown as forage in the south. If herbicides are not used it can be controlled by intense grazing and mowing for two years until the rhizomes are depleted. (CDFA, no year a; Lanini no year b). There are separate biotypes of Johnsongrass that have resistance to ACCase inhibitors, Dinitroanilines and ALS inhibitors (Heap et al., 2008).

Palmer amaranth (*Amaranthus palmeri*) is closely related to waterhemp and is the dominant pigweed in the Southwest. It is the most competitive and rapidly growing species of the weedy pigweeds and can reach a height of six feet (Steckel no year b). It is susceptible to herbicides when it is 4 to 6 inches tall (Scarpitti et al., 2007). Biotypes of Palmer amaranth have been identified with resistance to Dinitroanilines, photosystem II inhibitors, and ALS inhibitors (Heap et al., 2008).

Buckhorn Plantain (*Plantago lanceotata*) competes with crops for soil nutrients, water, and light and does well in droughts. It reproduces by seed and by tap root. Buckhorn plantain establishes slowly in alfalfa, but, once established, is difficult to control because of its extensive crown system (Wall and Whitesides, 2008). Glyphosate resistance is the only identified herbicide resistance in buckhorn plantain and has only been found in South Africa, so far (Heap et al., 2008).

Goosegrass (*Eleusine indica*) is an annual grass with an extensive root system that can produce 50,000 seeds per plant (Duble, no year). It is one of the five most troublesome weeds world-wide. It is found in agricultural fields, homeowner lawns, waste areas, roadsides, pastures, and golf courses. When it emerges with or shortly after a crop it can be a very competitive weed. Later in the growing season, it can produce enough biomass to hinder harvest (Steckel no year c). Some goosegrass biotypes exist that are known to be resistant to ACCase inhibitors, Bipyridiliums, Dinitroanilines, and ALS inhibitors. In Malaysia, a case of multiple resistance to ACCase inhibitors and glyphosate was found (Heap et al., 2008).

Junglerice (*Echinochloa colonum*) is a summer annual grass that is invasive in Tennessee, Hawaii, and Arizona (NPS 2007). It has little or no dormancy in tropical areas and germinates throughout the year. It can grow two to three feet high (Virginia Tech, no year). In Costa Rica, a biotype has been identified that has multiple resistance to ACCase inhibitors, ALS inhibitors, and ureas and amides. A glyphosate resistant biotype has been identified in Australia (Heap et al., 2008).

4.1.2 Traditionally Glyphosate Resistant Weeds

Ten weeds that are common in alfalfa and historically have some tolerance for glyphosate include bermudagrass, burning nettle, cheeseweed, common lambsquarters, field bindweed, filaree, large crabgrass, morningglory, nutsedge, and purslane. Each is briefly discussed below.

Bermudagrass (*Cynodon dactylon*) is a perennial grass that propagates through seed, root, or stem cuttings. If bermudagrass is cultivated, the soil should be dry because, if it is moist, the cut shoots will form new plants (Cudney and Elmore 2007). Bermudagrass is also grown as a forage crop (Undersander and Pinkerton 1988).

Burning nettle (*Urtica urens*) is a summer annual that flowers from June to November and is wind-pollinated. One plant can produce from 1,000 to 40,000 seeds. When left undisturbed in soil for six years, germination declined by 61 percent. However, 20 to 100 year-old seeds from excavations have been known to germinate. Seeds can also survive livestock digestive systems (Organic Garden 2007). Burning nettle stinging hairs contain histamine, formic acid, acetylcholine, acetic acid, butyric acid, leukotrienes, 5-hydroxytryptamine, and other irritants.

Dermal contact with the hairs leads to a mildly painful sting and itching or numbness for a period lasting from minutes to days (Thorne Research 2007). In Australia, a biotype resistant to photosystem II inhibitors has been identified (Heap et al., 2008).

Cheeseweed (*Malva neglecta*) is an annual or biennial dicot that reproduces from seeds. It is found on cultivated ground, new lawns, farmyards, and waste places (Mitich, no year). It is very competitive in alfalfa and, once established, is difficult to control. The fatty acids malvalic acid and sterculic acid may cause the plant to be toxic to horse, cattle, and sheep (Canevari 1997). Selenium or nitrate concentration has also been cited as the cause of toxicity (Hill 1993; USU, no year; Barnard, 1996).

Common lambsquarters (*Chenopodium album*) is a summer annual dicot that is adaptable to many environments. A plant can produce 100,000 seeds which can survive 30 to 40 years in soil (Lanini, no year c). Biotypes that are resistant to photosystem II inhibitors and ALS inhibitors have been identified in the United States (Heap et al., 2008). Glyphosate resistant lambsquarters has been reported in the Midwest and in a Madera, CA almond orchard (Cline 2004).

Field bindweed (*Convolvulus arvensis*) is a perennial dicot that reproduces by seed and vegetatively from deep-creeping roots and rhizomes. Young plants seldom produce seed in the first year, but one plant can produce 500 seeds. In fields, seeds can survive 20 years or more. Field binweed can harbor the viruses that cause potato X disease, tomato spotted wilt, and vaccinium false bottom. In addition, it contains tropane alkaloids and can cause intestinal problems in grazing horses (CDFA no year b).

Filaree (*Erodium cicutarium*) is a winter annual dicot that grows two to five inches high. It is adapted to a broad range of soil types and is found in oak woodlands, semi-desert grassland, desert shrublands, fields, lawns, and wasteplaces. Redstem filaree can be excellent forage for livestock and wildlife, but can cause bloating under heavy grazing (Pratt et al., 2002). It is competitive with crops and can cause yield reductions (Trainor and Bussan 2001).

Large crabgrass (*Digitaria sanguinalis*) is a summer annual that reproduces by seeds (Stritzke, no year). It is primarily a turfgrass weed, but can be founding thinning alfalfa stands (Elmore 2002). A biotype with multiple resistance to ACCase inhibitors and ALS inhibitors has been identified in Australia. Photosystem II inhibitor resistant biotypes have also been identified (Heap et al., 2008).

Morning glory (*Ipomoea purpurea*) is a perennial climbing vine that reproduces by seed (Pittwater Council, no year). It is a problem in crops because of competition. Morning glory seeds are toxic to humans (Filmer, no year). Morning glory foliage is toxic to livestock due to nitrates. Symptoms of acute nitrate poisoning are trembling, staggering, rapid breathing, and death. Chronic poisoning may result in poor growth, poor milk production and abortions. In cattle, there is evidence that vitamin A storage is affected (Robinson and Alex 1989).

Nutsedge (*Cyperus* spp.) is a hardy weed due to tubers that grow 8 to 14 inches below the ground and, when mature, can re-sprout 10 to 12 times after cutting before tuber resources are depleted. In addition, many herbicides are not translocated to tuber, and, therefore, do not

effectively control growth (Wilen et al., 2003). Alfalfa should not be planted in a field where nutsedge is a known problem (Canevari et al., 2003). In a study in California, nutsedge was reduced 96 to 98 percent using crop rotation and herbicides. The rotation was two years alfalfa with applications of EPTC herbicide, two years of barley double-cropped with corn and application of thiocarbamate herbicide, and two years of barley followed by fallow glyphosate applications (Canevari et al., 2007). Biotypes of *Cyperus difformis* that are resistant to ALS inhibitors have been found in California and globally (Heap et al., 2008).

Purslane (*Portulaca oleracea*) is a summer annual dicot that produces 240,000 seeds per plant and can survive five to 40 years. It can re-root after cultivation or hoeing, so it is difficult to control mechanically. It is a minor crop in the United States because it is edible and is used in ethnic cooking. In other crops, it is a weed because of competition (Cudney et al., 2007).

4.1.3 Mechanisms of Glyphosate-Tolerance

Glyphosate inhibits 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, which is a key enzyme in the shikimate pathway in plants and is required for plant growth. The effects of glyphosate can be stopped in several ways (Cerdeira and Duke, 2006; Stoltenberg and Jeschke, no year; Nandula et al., 2005):

Resistant EPSP synthase - A version of EPSP synthase that is not affected by glyphosate has been found in bacteria (*Agrobacterium*) and has been transferred into crop plant genomes. Also, the maize version of EPSP synthase has been modified by site directed mutagenesis to be resistant to glyphosate. A version of EPSP synthase with decreased binding to glyphosate has been found in the weed goosegrass (*Eleucine indica*).

Degrade glyphosate - A glyphosate-degrading enzyme has been found in bacteria (*Ochrobactrun anathropi*) and has been transferred into crop plant genomes.

Inactivate glyphosate - An enzyme found in bacteria (*Bacillus licheniformis*) has a weak ability to inactivate glyphosate through N-acetylation. The efficiency of this enzyme was increased by directed evolution in the lab and, when transferred to plants, confers resistance to glyphosate in field settings. A fungal gene encoding glyphosate decarboxylase has been discovered and patented for eventual use in crop plants.

Altered translocation of glyphosate – There is limited evidence that, in some glyphosate resistant ryegrass, glyphosate accumulates in mature leaf tissue rather than in the growing parts. Although the mechanism of resistance in horseweed is unknown, translocation experiments suggest that resistant biotypes do not translocate glyphosate to the growing parts of the plant (e.g., roots, young leaves, and crown).

Other – Resistant plants exist for which the mechanism of glyphosate resistance is not known. In addition, it is likely that there are mechanisms of resistance that have yet to evolve.

4.2 Weed Shifts in GT Alfalfa

Adopting new weed control strategies eventually leads to shifts in the weeds that are of greatest concern. Weed shifts can occur due to changes in tillage, irrigation, soil fertility, planting date, crop rotation, and herbicide use (Hilgenfeld et al., 2004). Changes to a no-till system results in a more diverse seedbank. Within weedy species variations in characteristics help weeds escape or tolerate weed management. These characteristics include seed dormancy, emergence patterns, growth plasticity, life cycle, life duration, shade tolerance, late-season competitive ability, seed dispersal mechanisms, and morphological and physiological variations (Hilgenfeld et al., 2004).

Because weed seedbanks in the soil can contain large reservoirs of dormant weed seed, short-term studies (a few years) might not detect the full potential shift in weed communities (Harker et al., 2005). However sometimes weeds shift can be observed within a few years. For example, in a field trial in an established GT alfalfa stand in the Southwest (San Joaquin Valley) burning nettle was not controlled and the population of burning nettle increased significantly over the three-year trail period (Canevari et al., 2004; Van Deynze et al., 2004). Tank mixtures with Velpar (hexazinone) or paraquat controlled burning nettle. Weeds that are difficult to control with glyphosate, such as dodder and cheeseweed, may need to be treated early and require a second application. Van Deynze et al (2004) recommend that the best way to prevent weed shifts is to avoid using the same herbicide year after year, rotate herbicides and crops, and include non-herbicide strategies to control weeds.

Puricelli and Tuesca (2005) found that continuous (once before planting, once at 40 days after planting, once in winter fallow in August) glyphosate application in field studies on three crop rotation sequences and two tillage systems lead to quantitative and qualitative changes in weed communities. They found that glyphosate application was a more important factor than crop sequence to explain weed community changes in summer crops. They also predicted that continual glyphosate application for longer than the five years in their study might lead to the development or higher increases in abundance of weeds tolerant to glyphosate. Weed species diversity in conventional versus no-tillage plots did not differ significantly.
Harker et al., (2005) reported that field studies of spring wheat-canola-spring wheat rotations of various combinations of GT and non-GT varieties under conventional tillage or low soil disturbance direct seeding systems indicate that weed community shifts are dependent on rotation pattern in a site-dependent manner. In the western Canada field locations, within 3 years, crop systems without GT varieties were associated (using canonical discriminant analysis) with green foxtail, redroot pigweed, sowthistle spp., wild buckwheat, and wild oat. The specific weeds associated with all GT variety systems included Canada thistle at the Brandon site, henbit at the Lacombe site, and volunteer wheat, volunteer canola, and round-leaved mallow at the Lethbridge site. One surprising finding was that high variability in wild buckwheat between the systems. Glyphosate is not very effective on wild buckwheat, so the authors propose that wild buckwheat seed production or viability may be restricted by glyphosate more than the wild buckwheat biomass. Therefore after glyphosate application the plant may appear visually robust, but its ability to reproduce has been effected, so in following years less wild buckwheat is observed (Harker et al., 2005).

It is plausible that the 18 weeds discussed in section 4.1 are the first candidates for weed shifts in GT alfalfa. However, as discussed in the studies summarized above, weed shifts are dependent on the composition of the weed seedbank in the soil and surrounding sources of weeds.

4.2.1 Weed Management Options

Weed management strategies in organic alfalfa systems, conventional alfalfa systems, and glyphosate-tolerant alfalfa systems differ. Management options for conventional systems include (Nandula et al., 2005; Guerena and Sullivan 2003):

- Chemical (See table G-6)
  - Alternating herbicides with different modes of action
  - Tank mixing herbicides
  - Sequences of herbicides
  - Application timing
- Cultural
  - Rotation between GT cultivars and non-GT cultivars
  - Winter crops in rotation
  - Companion crops/co-cultivation/interseeding/nurse crop)
  - Cover crops (smother crops) (prior to planting alfalfa)
  - Field scouting for early detection
  - Monitor for weed species and population shifts
- Mechanical
- Tillage cultivation

Organic alfalfa systems can use the cultural and mechanical strategies (except for use of GT cultivars). Nurse crops of peas or oats produce good hay for the horse market (Guerena and Sullivan 2003). GT alfalfa systems can use all of the strategies of conventional systems plus application of glyphosate directly on growing alfalfa. Options for rotating between GT cultivars and non-GT cultivars are reduced with GT alfalfa, since GT corn and GT soybean are popular rotation crops for alfalfa.

Cutting intervals affect weed infestation. For example, if alfalfa is cut too frequently (20 to 25 days) there is not enough time for root storage of carbohydrates so growth after cutting is not vigorous and weeds have a competitive advantage. However sometimes early harvest can rescue a heavily weed-infested new stand if the weeds are beyond the stage of optimum herbicide treatment (Canevari et al, 2007). Alternating long and short intervals between cuttings enables alfalfa to maintain root reserves so plants can recover from defoliation quickly and more vigorously compete with weeds (Canevari et al, 2007).

4.3 Distribution of Glyphosate Resistant Weeds

Table G-8 shows that currently 19 U.S. states are affected by glyphosate resistant weeds. The majority of new glyphosate resistant weeds are located in the Southeast and Midwest. The overlap with the major alfalfa producing states in the Intermountain regions seems to be minimal at this point (table G-6). However, given that there is overlap between glyphosate resistant weed locations and alfalfa hay acreage there is potential for rapid shifts of glyphosate resistant weeds

into GT alfalfa fields if GT alfalfa were to be widely adopted. California is a concern because glyphosate resistant weeds are present and alfalfa is a major crop in California. More detailed records of local weed infestations may be kept by state extension offices.

Table G-8. Glyphosate-Resistant Weed Infestations by State (Heap et al., 2008)

State	Weed species	~ Number of Sites in State Infested	~ Number of Acres in State Infested	Situation	Year Reported
Arkansas	***Conyza canadensis*** Horseweed	6-10 increasing	1,001-10,000 increasing	Cotton	2003
	Ambrosia artemisiifolia Common Ragweed	1	11-50	Soybean	2004
	Ambrosia trifida Giant Ragweed	6-10 increasing	101-500 increasing	Soybean	2005
	Amaranthus palmeri Palmer Amaranth	1 increasing	unknown	Soybean	2006
	Sorghum halepense Johnsongrass	1	unknown	Soybean	2007
California	***Lolium rigidum*** Rigid Ryegrass	11-50 increasing	1,001-10,000 increasing	Almonds	1998
	Conyza canadensis Horseweed	1	unknown	Roadside	2005
	Conyza bonariensis Hairy Fleabane	2-5	unknown	Roadside	2007
Delaware	***Conyza canadensis*** Horseweed	101-500	10,001-100,000	Soybean	2000
Georgia	***Amaranthus palmeri*** Palmer Amaranth	101-500 increasing	100,001-1,000,000 increasing	Cotton Soybean	2005
Illinois	***Conyza canadensis*** Horseweed	1,001-10,000 increasing	10,0001-1,000,000 increasing	Soybean	2005
	Amaranthus rudis Common Waterhemp***	1 increasing	51-100 increasing	Corn Soybean	2006
Indiana	***Conyza canadensis*** Horseweed	2-5 increasing	101-500 increasing	Soybean	2002
	Ambrosia trifida Giant Ragweed	1 increasing	11-50 increasing	Soybean	2005
Kansas	***Conyza canadensis*** Horseweed	51-100 increasing	10,001-100,000 increasing	Cotton Soybean	2005
	Ambrosia trifida Giant Ragweed	2-5 increasing	501-1,000 increasing	Soybean	2006
	Amaranthus rudis Common Waterhemp	2-5 increasing	101-500 increasing	Soybean	2006
	Ambrosia artemisiifolia Common Ragweed	1 increasing	11-50 increasing	Soybean	2007
Kentucky	***Conyza canadensis*** Horseweed	2-5 increasing	51-100 increasing	Soybean	2001
Maryland	***Conyza canadensis*** Horseweed	6-10 increasing	501-1,000 increasing	Soybean	2002
Michigan	***Conyza canadensis*** Horseweed	1 increasing	51-100 increasing	Nursery	2007

Minnesota	***Ambrosia trifida*** Giant Ragweed	2-5 increasing	101-500 increasing	Soybean	2006
	Amaranthus rudis Common Waterhemp	2-5 increasing	51-100 increasing	Soybean	2007
Mississippi	***Conyza canadensis*** Horseweed	101-500 increasing	1,001-10,000 increasing	corn, cotton, rice, and soybean	2003
	Lolium multiflorum Italian Ryegrass	unknown	1,001-10,000 increasing	Cotton Soybean	2005
Missouri	***Conyza canadensis*** Horseweed	101-500 increasing	10,001-100,000 increasing	Cotton	2002
	Ambrosia artemisiifolia Common Ragweed	1	11-50	Soybean	2004
	Amaranthus rudis Common Waterhemp**	1 increasing	1,001-10,000 increasing	Corn Soybean	2005
New Jersey	***Conyza canadensis*** Horseweed	6-10 increasing	101-500 increasing	Soybean	2002
North Carolina	***Conyza canadensis*** Horseweed	2-5 increasing	6-10 increasing	Cotton	2003
Ohio	***Conyza canadensis*** Horseweed	101-500 increasing	1,001-10,000 increasing	Soybean	2002
	Conyza canadensis Horseweed*	2-5 increasing	101-500 increasing	Soybean	2003
	Ambrosia trifida Giant Ragweed	2-5 increasing	101-500 increasing	Soybean	2004
Oregon	***Lolium multiflorum*** Italian Ryegrass	1 stable	1-5 stable	Orchards	2004
Pennsylvania	***Conyza canadensis*** Horseweed	2-5 increasing	101-500 increasing	Soybean	2003
Tennessee	***Conyza canadensis*** Horseweed	501-1,000 increasing	>2,000,000 increasing	Cotton Soybean	2001
	Amaranthus palmeri Palmer Amaranth	2-5 increasing	101-500 increasing	Cotton	2006
	Ambrosia trifida Giant Ragweed	101-500 increasing	1,001-10,000 increasing	Cotton Soybean	2007

* resistant to chlorimuron-ethyl, cloransulam-methyl, and glyphosate ** resistant to acifluorfen-Na, cloransulam-methyl, fomesafen, glyphosate, imazamox, imazethapyr, and lactofen *** resistant to chlorimuron-ethyl, glyphosate, and imazethapyr

Monsanto's guidance for weed resistance management in GT alfalfa is as follows (Monsanto 2008):

- Scout fields before and after each herbicide application.
- Use the right herbicide product at the right rate and at the right time.
- To control flushes of weeds in established alfalfa, make applications of Roundup WeatherMAX herbicide at 22 to 44 oz/A before weeds exceed 6", up to 5 days before cutting.
- Use other herbicide products tank-mixed or in sequence with Roundup agricultural herbicide if appropriate for the weed control program.
- Report repeated non-performance to Monsanto or your local retailer.

4.4 Summary of Findings

At least 129 different weed species are identified as minor or major problems in alfalfa. Out of 14 new glyphosate resistant weeds found since 1998, eight are known to be weeds in alfalfa. Out of at least 21 weeds that have natural resistance to glyphosate, ten are known to be a problem in alfalfa. These 18 weeds that are both resistant to glyphosate and traditionally listed as problems in alfalfa include: common ragweed, horseweed, Italian ryegrass, Johnsongrass, Palmer Amaranth, buckhorn plantain, goosegrass, junglerice, bermudagrass, burning nettle, cheeseweed, common lambsquarters, field bindweed, filaree, large crabgrass, morningglory, nutsedge, and purslane. Although the composition of weed shifts is based on the local seedbank, these 18 weeds are candidates for becoming more prevalent than GT sensitive weeds in rotations that include GT alfalfa.

Mechanisms of glyphosate resistance include resistant EPSP synthase, degradation of glyphosate, inactivation of glyphosate, and altered translocation of glyphosate.

Nineteen states and over two million acres of cropland are infested with new glyphosate resistant weeds. The heaviest infestation is in the Southeast and Midwest. Overlap with the major alfalfa producing states in the Intermountain regions seems to be minimal at this point. However, given that there is overlap between glyphosate resistant weed locations and alfalfa hay acreage there is potential for rapid shifts of glyphosate resistant weeds into GT alfalfa fields if GT alfalfa were to be widely adopted. California is a concern because glyphosate resistant weeds are present and alfalfa is a major crop in California.

Weeds are controlled in conventional alfalfa with chemicals (herbicides), cultural methods (rotation, companion crops, monitoring), and mechanical methods (tillage). The cultural and mechanical methods are permitted for organic farmers. GT systems allow for the use of one additional herbicide, glyphosate.

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Appendix G-2. Literature Search

1.0 Literature Search Strategy

The following literature search was done for two of the technical reports:

Effects of Glyphosate-tolerant weeds in agricultural systems (former title: Increase in RR resistant weeds in crops)

Effects of Glyphosate-tolerant weeds in non-agricultural ecosystems (former title: Increase in RR resistant weeds in non-crop ecosystems)

1.1 Purpose

The purpose of this literature search is to locate references about the potential impacts of glyphosate-tolerant weeds in agricultural systems and in natural ecosystems.

The following DIALOG databases were included in the search:
- File 10:AGRICOLA 70-2008/Jun
- (c) format only 2008 Dialog
- File 156:ToxFile 1965-2008/Jun W2
- (c) format only 2008 Dialog
- File 266:FEDRIP 2008/Feb
- Comp & dist by NTIS, Intl Copyright All Rights Res
- File 245:WATERNET(TM) 1971-2008Apr
- (c) 2008 American Water Works Association

File 55:Biosis Previews(R) 1993-2008/Jun W2
- (c) 2008 The Thomson Corporation

File 6:NTIS 1964-2008/Jun W4
- (c) 2008 NTIS, Intl Cpyrght All Rights Res

File 41:Pollution Abstracts 1966-2008/May
- (c) 2008 CSA.

File 40:Enviroline(R) 1975-2008/Apr
- (c) 2008 Congressional Information Service

File 76:Environmental Sciences 1966-2008/Jun
- (c) 2008 CSA.

File 24:CSA Life Sciences Abstracts 1966-2008/Mar
- (c) 2008 CSA.

File 117:Water Resources Abstracts 1966-2008/Mar
- (c) 2008 CSA.

File 144:Pascal 1973-2008/Jun W2
- (c) 2008 INIST/CNRS

File 50:CAB Abstracts 1972-2008/Apr

□ (c) 2008 CAB International
File 44:Aquatic Science & Fisheries Abstracts 1966-2008/Mar
(c) 2008 CSA.

□ File 71:ELSEVIER BIOBASE 1994-2008/May W4
□ (c) 2008 Elsevier B.V.
File 143:Biol. & Agric. Index 1983-2008/Apr
(c) 2008 The HW Wilson Co
□ File 203:AGRIS 1974-2008/Feb
Dist by NAL, Intl Copr. All rights reserved

Descriptions of these files are available at http://library.dialog.com/bluesheets/.

1.2 Scope of Search

The search focused on any published references between 2000 and the present. A list of titles was screened followed by screening of abstracts for relevant titles. There were no limits on language for titles but only English language publications were retrieved for evaluation.

1.3 Keywords

A list of search parameters is listed below.

Synonyms of key topic
Glyphosate toleran*
Glyphosate resistan*
Roundup® Ready

Key words in combination with key topic Weed management Weed mitigation Weed control
Alfalfa
Medicago
Evolution

1.4 Results

S1 4711 GLYPHOSATE()(TOLERAN? OR RESIST?) OR ROUNDUP()READYS2 3534 S1/2000:2008S3 121649 ALFALFA OR MEDICAGO S4 1796168 WEED? OR EVOLUTION
S5 27 S2 AND S3 AND S4
S6 14 RD S5 (unique items)

□ 7/K,6/1 (Item 1 from file: 144)DIALOG(R)File 144:(c) 2008 INIST/CNRS. All rts. reserv.
17594709 PASCAL No.: 06-0183713
Alfalfa management in no-tillage corn
2006
Glyphosate-*resistant* corn was no-till planted into *alfalfa* that wasin the early bud stage (UNCUT) or had been cut 3 to 4 d earlier and baledfor hay (CUT). *Alfalfa* control and corn yield were measured in nontreatedplots as well as plots treated with.....or tank-mixed with 2,4-D or dicamba applied at planting (AP) or POST.*Alfalfa* control was greater for all AP treatments of UNCUT compared toCUT *alfalfa*. Glyphosate plus dicamba applied AP controlled *alfalfa*better than the other AP treatments resulting in increased corn yieldcompared with other

AP...Postemergence applications of glyphosate alone ortank-mixed with 2,4-D or dicamba controlled *alfalfa* better 6 weeks after treatment than AP applications of the same herbicides; however, corn yield..... same herbicides. Corn yield averaged 13% higher following herbicideapplications to UNCUT compared with CUT *alfalfa*, so the value of *alfalfa* hay must be weighed against the loss of corn yield when makingdecisions concerning the management of an *alfalfa*-corn rotation.Descriptors: Zero tillage; *Weed* control; *Weed* science; *Medicago* sativa

7/K,6/2 (Item 2 from file: 10)DIALOG(R)File 10:(c) format only 2008 Dialog. All rts. reserv.4712341 43956730 Holding Library: AGL

Comparing *Roundup* *Ready* and Conventional Systems of *Alfalfa* Establishment

2007

URL: http://dx.doi.org/10.1094/FG-2007-0724-01-RS

Roundup *Ready* (RR) technology provides a new approach for *weed*

control during *alfalfa* (*Medicago* sativa L.) establishment. We determined the effect of RR and conventional establishment systems on*alfalfa* yield, *weed* yield, and forage quality when *alfalfa* was established using solo-seeding or oat mulch methods. A RR system was a RR*alfalfa* in combination with glyphosate (Roundup) and a conventional system was a non-RR variety with imazamox (Raptor). Non-RR and RR alfalfaswere also seeded with an oat companion crop. *Alfalfa* yields, plantpopulations, and forage quality were similar for the RR and conventionalsystems within solo-seeding and oat establishment methods in the seedingyear. Total seeding-year *alfalfa* yield was greater when solo-seeded usingan herbicide than when seeded with an oat companion crop harvested at boot.*Alfalfa* yield for the oat mulch and oat companion crop treatments werenot consistently different over...

DESCRIPTORS: *Medicago* sativa.....*alfalfa*; .....*weeds*; .....*weed* control;
Identifiers: *Roundup* *Ready* *alfalfa*Section Headings: F120 PLANT PRODUCTION-FIELD CROPS; F900 *WEEDS*

7/K,6/3 (Item 3 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.18335235 BIOSIS NO.: 200510029735 Influence of *Roundup* *Ready* (R) soybean production systems and

glyphosate application on pest and beneficial insects in wide-row soybean*2004* ABSTRACT: *Roundup* *Ready* (R) soybean, Glycine max (L.) Merrill, in

widerow planting systems were investigated in 1997 and...

...pest and beneficial insects. Populations of adult bean leaf beetle,Cerotoma trifurcata (Forster), and threecornered *alfalfa* hopper,Spissistilus festinus (Say), and larvae of green cloverworm, Hypenascabra (F.), and velvetbean caterpillar, Anticarsia gemmatalis (Hubner),were not affected by genetically altered *Roundup* *Ready* soybean or byapplications of glyphosate. Numbers of adult big-eyed bug, Geocoris punctipes (Say...influenced G. punctipes densities in 3 of 11 weeks. These

1.0 effects were attributed to increased *weed* densities having a positive effect on G.punctipes numbers during this 3-week period. Increased...

...1 of 2 years. These elevated numbers, however, were also related tohigher densities of *weeds*. The results presented herein demonstratedthat the *Roundup* *Ready* soybean system, including applications ofglyphosate, had no detrimental effects on pest and beneficial insects.....ORGANISMS: Spissistilus festinus {threecornered *alfalfa* hopper}

(Homoptera.....strain-*Roundup* *Ready*;

7/K,6/4 (Item 4 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.17883376 BIOSIS NO.: 200400254133 Influence of *Roundup* *Ready* soybean production systems and glyphosate

application on pest and beneficial insects in narrow-row soybean.*2004* ABSTRACT: *Roundup* *Ready*(R) soybeans, Glycine max (L.) Merrill, in

narrow-row planting systems were investigated in 1998...

...numbers for meaningful analysis included adult bean leaf beetle,Cerotoma trifurcata (Forster); adult three-cornered *alfalfa* hopper,Spissistilus festinus (Say); adult big-eyed bug, Geocoris punctipes (Say), and; larvae of green...

...C. trifurcata, S. festinus, P. scabra and A. gemmatalis were not reducedin genetically altered *Roundup* *Ready* soybean, or by recommended (bylabel) or delayed applications of glyphosate. Numbers of G. punctipesalso were not reduced in *Roundup* *Ready* soybean, but were reduced byrecommended applications of glyphosate during weeks three and four
following.....been indirectly reduced by glyphosate within sample weeks two
and threebecause of variations in *weed* densities after treatment with the
herbicide.
...ORGANISMS: Spissistilus festinus {*alfalfa* hopper} (Homoptera.....oil crop, *Roundup* *Ready* line...
Roundup *Ready* productionsystems.....*weed* densities

7/K,6/5 (Item 5 from file: 10)DIALOG(R)File 10:(c) format only 2008 Dialog. All rts. reserv.4598987
43898530 Holding Library: AGL

Evaluating Glyphosate Treatments on *Roundup* *Ready* *Alfalfa* for Crop
2.0 Injury and Feed Quality*2007* URL: http://dx.doi.org/10.1094/FG-2007-0201-01-RS*Weed* control is one of the factors that impact *alfalfa* producers,
with negative effects on quality often in the year of establishment.Glyphosate is a broad-spectrum herbicide that controls many troublesomeannual and perennial *weeds* , and new cultivars that are tolerant of glyphosate application have been developed. The crop response of glyphosateon these new varieties has not been reported. This research examined*alfalfa* tolerance under field conditions, and high rates were used tochallenge the plants to determine.....ranging from 0.75 to 3 lb a.e./acre sprayed before each of four *alfalfa* harvests had no meaningful crop injury in the establishment yearor in the subsequent two...of 9 lb a.e./acre over a 3-year period caused noreduction in *alfalfa* yield or nutritive value at any cutting in any of thethree years.
DESCRIPTORS: *Medicago* sativa.....*alfalfa*;
.....postemergent *weed*control;Identifiers: *Roundup*
Ready *alfalfa*

7/K,6/6 (Item 6 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts.
reserv.0020265061 BIOSIS NO.: 200800312000 Establishment systems for *glyphosate*-*resistant*
*alfalfa**2008* ABSTRACT: Glyphosare-resistant *alfalfa* offers new *weed* control options for *alfalfa* establishment. Field studies were conducted in 2004 and 2005 to determine the effect of establishment method and *weed* control method on forage production and *alfalfa* stand establishment. Seedingmethods included clear seeding and companion seeding with oats. Herbicidetreatments included...reduce forage yield or stand density in 2004. No
glyphosate injury was observed in 2005. *Weed* control with glyphosate was
3.0 more consistent than with imazamox or imazamox + clethodim. In 2004, total seasonal forageyield, which consisted of *alfalfa*, *weeds*, and oats (in sometreatments), was the highest where no herbicide was applied in the...
...was reduced where herbicides were applied in both establishment systems.In 2005, seeding method or *weed* control method did not affect totalseasonal forage production. *Alfalfa* established with the clear-seededmethod and treated with glyphosate yielded the highest *alfalfa* dry

matter in both years. Imazamox injury reduced first-harvest *alfalfa*yield in the clear-seeded system in both years. When no herbicide wasapplied, *alfalfa* yield was higher in the clear-seeded system. The oatcompanion crop suppressed *alfalfa* yield significantly in both years.*Alfalfa* established with an oat companion crop had a lower *weed*biomass than the clear-seeded system where no herbicide was applied in both
years....ORGANISMS: *Medicago* sativa {*alfalfa*} (Leguminosae)

7/K,6/7 (Item 7 from file: 10)DIALOG(R)File 10:(c) format only 2008 Dialog. All rts. reserv.4823604
44034732 Holding Library: AGL
Glyphosate-*resistant* crops: adoption, use and future considerations*2008* URL: http://dx.doi.org/10.1002/ps.1501BACKGROUND: *Glyphosate*-*resistant* crops (GRCs) were first introduced
in the United States in soybeans in 1996. Adoption has.....13.2 million ha), cotton (5.1 million ha), canola (2.3 million ha) and*alfalfa* (0.1 million ha). Currently, the USA, Argentina, Brazil andCanada have the largest plantings of GRCs. Herbicide use patterns wouldindicate that over 50% of *glyphosate*-*resistant* (GR) maize hectares and70% of GR cotton hectares receive alternative mode-of-action treatments... ...production system. Tillage

was likely used for multiple purposes rangingfrom seed-bed preparation to *weed* management.CONCLUSION: GRCs representone of the more rapidly adopted *weed* management technologies in recenthistory. Current use patterns would indicate that GRCs will likely continueto be a popular *weed* management choice that may also include the use ofother herbicides to complement glyphosate. Stacking...

□ 7/K,6/8 (Item 8 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.18808410 BIOSIS NO.: 200600153805 *Glyphosate*-*resistant* crops: History, current status, and future*2004*
...ORGANISMS: *alfalfa* (Leguminosae MISCELLANEOUS TERMS: *weed* management...

□ 7/K,6/9 (Item 9 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0009113458 CAB Accession Number: 20063199990
□ *Glyphosate*-*tolerant* *alfalfa* is compositionally equivalent to conventional *alfalfa* (*Medicago* sativa L.).Publication Year: 2006 *Glyphosate*-*tolerant* *alfalfa* (GTA) was developed to withstand
□ over-the-top applications of glyphosate, the active ingredient in...
□ ... United States during the 2001 and 2003 field seasons along with controland other conventional *alfalfa* varieties for compositional assessment.Field trials were conducted using a randomized complete block design withfour replication blocks at each site. *Alfalfa* forage was harvested atthe late bud to early bloom stage from each plot at...
... from GTA J101 x J163 is compositionally equivalent to forage from the control and conventional *alfalfa* varieties. IDENTIFIERS: *alfalfa*; ....*weedicides*; ...*weedkillers*...*Medicago*sativa

□ 7/K,6/10 (Item 10 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0007976368 CAB Accession Number: 20003004906
Roundup *Ready* *alfalfa*.Publication Year: 2000 Genetic engineering has been used to develop *Roundup* *Ready* SUP TM
□ (i.e. glyphosate herbicide tolerant) *alfalfa*. There is a significant interest in the use of RR *alfalfa* to improve options for effective, crop-safe *weed* control, both for establishment and for the control of tough perennial *weeds* in established stands. The project to develop *Roundup* *Ready* *alfalfa* is a collaboration between Monsanto, Montana State University and Forage Genetics International (FGI). Transformation,

event...
... application of Roundup Ultra. Applications at later reproductive stagesreduced seed yield. The current RR *alfalfa* timeline predicts thecommercial release of a wide range of RR *alfalfa* varieties in 2004.ORGANISM DESCRIPTORS: *Medicago* sativa...CABICODES: *Weeds* and Noxious Plants

□ 7/K,6/11 (Item 11 from file: 10)DIALOG(R)File 10:(c) format only 2008 Dialog. All rts. reserv.4660649 43931909 Holding Library: AGL
Is *Roundup* *Ready* *alfalfa* right for you
2007
URL: http://cropwatch.unl.edu/
DESCRIPTORS: *alfalfa*; .....*weed* control;
Section Headings: F120 PLANT PRODUCTION-FIELD CROPS; H000

PESTICIDES-GENERAL; F200 PLANT BREEDING; F900 *WEEDS*

7/K,6/12 (Item 12 from file: 10)DIALOG(R)File 10:(c) format only 2008 Dialog. All rts. reserv.

□ 4442412 30961704 Holding Library: WYU; AGX *Roundup* *Ready*.reg. *alfalfa* a new technology for high plains hay

producers / Stephen D. Miller ... [et al.]*2006* URL:
http://www.uwyo.edu/CES/PUBS/B1173.pdfDESCRIPTORS:
Alfalfa; .....*Weeds*;

□ 7/K,6/13 (Item 13 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0008500330 CAB Accession Number: 20033167182

□ Seed bank changes following the adoption of *glyphosate*-*tolerant* □ crops.Publication Year: 2003 *Weed* seed banks in long-term tillage/rotation plots were sampled in the early spring of 1999 and 2002, before and after the adoption of*glyphosate*-*tolerant* soyabean (Glycine max) and maize (Zea mays),respectively. Canonical discriminant analysis was used to characterize.....first canonical function was strongly associated with crop rotation. Themaize-oat (Avena sativa)-lucerne (*Medicago* sativa) rotation clustered separately from continuous maize and maize-soyabean rotations when visualized in a...05), suggesting that practices used in the varyingsystems selected for divergent communities. After employing *glyphosate**tolerant* maize and soyabean varieties for three growing seasons (1999-2001), differences incommunity composition between...use of a single, non-selective herbicideacross all treatments resulted in a more homogeneous *weed* seed bankcommunity.
...ORGANISM DESCRIPTORS: *Medicago*; ...

S9 9600 HERBICIDE? ?()(TOLERAN? OR RESIST?)/2000:2008S3 121649 ALFALFA OR MEDICAGO S4 1796168 WEED? OR EVOLUTION S5 27 S2 AND S3 AND S4 S10 35 S9 AND S3 AND S4 NOT S5 S11 20 RD S10 (unique items)

□ 12/K,6/1 (Item 1 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.18075829 BIOSIS NO.: 200400443748 Development of 2,4-D-resistant transgenics in Indian oilseed mustard(Brassica juncea)*2004* ...ABSTRACT: monooxygenase, cloned downstream to the 35S promoter along with a leader sequence from RNA4 of *alfalfa* mosaic virus (AMV leader □ sequence), for improved expression of the transgene in plant cells.Southern... ...available transgenic lines can be used for testing the potential of 2,4-D in *weed* control including the control of parasitic *weeds* (Orobanche spp) of mustard and for low-till cultivation of mustard.
ORGANISMS: *Alfalfa* mosaic virus (Bromoviridae...vegetable crop,

herbicide *resistant* transgenic line.....pest, *weed*

□ 12/K,6/2 (Item 2 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0008797522 CAB Accession Number: 20053050074

□ Efficacy of imidazolinone herbicides applied to imidazolinone-resistant maize and their carryover effect on rotational crops.Publication Year: 2005 ... a 31% petroleum hydrocarbon adjuvant at 125 and 250 mL ha SUP -1 , □ respectively. Overall *weed* control varied from 85%, up to 95%. *Weed*species controlled were Setaria sp., Chenopodium album , Solanum sp.,Amaranthus retroflexus and Digitaria sanguinalis , and... ...to low, was the following: Beta vulgaris > Capsicum annum > Lycopersicumesculentum > Cucumis melo > Hordeum vulgare > *Medicago* sativa > Loliummultiflorum > Avena sativa > Pisum sativum > Allium cepa > Zea mays ....DESCRIPTORS: *herbicide* *resistance*; .....*weed* control.....*weeds*...ORGANISM DESCRIPTORS: *Medicago*; ...

□ 12/K,6/3 (Item 3 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0009065754 CAB Accession Number: 20063137864

□ Influence of forage legume species, seeding rate and seed size on competitiveness with annual ryegrass (Lolium rigidum) seedlings.Publication Year: 2006 ... as short-term forage crops are an important non-chemical option for the control of *herbicide*-*resistant* annual ryegrass (Lolium rigidum L.). The relative ability of 5 annual forage legume species (Trifoliumsubterraneum L., T. michelianum Savi., T. alexandrinum L., *Medicago*murex Wild and Vicia benghalensis L.) to suppress annual ryegrassseedlings was examined in a.....DESCRIPTORS: *weed* control ...ORGANISM DESCRIPTORS: *Medicago* murex

□ 12/K,6/4 (Item 4 from file: 156)DIALOG(R)File 156:(c) format only 2008 Dialog. All rts. reserv.3840082
NLM Doc No: 12852606
Influence of *herbicide* *tolerant* soybean production systems on insectpest populations and pest-induced crop damage.Jun *2003*
Conventional soybean *weed* management and transgenic *herbicide*-*tolerant* management were examined to assess their effects on soybeaninsect pest populations in south Georgia..... leafhopper, Empoasca fabae (Harris), and grasshoppers Melanoplus spp.were more numerous on either conventional or *herbicide*-*tolerant* varieties on certain dates, although these differences were not consistentthroughout the season. Soybean looper, Pseudoplusia includens (Walker),threecornered *alfalfa* hopper, Spissistilus festinus (Say), and whitefringed beetles, Graphognathus spp , demonstrated no varietal preference in this study. Few *weed* treatment differences were observed,but if present on certain sampling dates, then pest numbers were higher inplots where *weeds* were reduced (either postemergence herbicides or preplant herbicide plus postemergence herbicide). The exception to this*weed* treatment effect was grasshoppers, which were more numerous in *weedy* plots when differences were present. In post emergence herbicideplots, there were no differences in...the conventional herbicides (e.g.,Classic, Select, Cobra, and Storm) compared with specific gene-inserted*herbicide*-*tolerant* materials (i.e., Roundup and Liberty).Defoliation, primarily by velvetbean caterpillar, was different betweensoybean..... We did not observe differences in seasonal abundance of arthropod pestsbetween conventional and transgenic *herbicide*-*tolerant* soybean.

□ 12/K,6/5 (Item 5 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0008298057
CAB Accession Number: 20023152152
Effect of herbicide treatment on the productivity of some annual pasturelegumes.
Book Title: 13th Australian *Weeds* Conference: *weeds* "threats now and forever?", Sheraton Perth Hotel, Perth, Western Australia, 8-13September 2002: papers and proceedings
Publication Year: 2002

... seed production of 11 pasture legume cultivars (Trifolium subterraneum cultivars Dalkeith and Urana, burr medic [*Medicago*polymorpha] cv. Santiago, French serradella [Ornithopus sativus] cv.Cadiz, yellow serradella [O. compressus] cv. Charano.....DESCRIPTORS: *herbicide* *resistance*; .....*weed* control.....*weeds*...ORGANISM DESCRIPTORS: *Medicago* polymorpha

□ 12/K,6/6 (Item 6 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.18860532 BIOSIS NO.: 200600205927

Effects of Artemisia afra leaf extracts on seed germination of selected crop and *weed* species
2005
ABSTRACT: *Herbicide* *resistance* in *weeds* is a phenomenon threateningsustainable cereal production in the winter rainfall region of SouthAfrica. Every possible *weed* control measure that may be used tocomplement chemical *weed* control measures should be investigated. Theeffect of aqueous leaf extracts of the aromatic shrub African wormwood(Artemisia afra) on germination of selected crop and *weed* species wereinvestigated. The selected plant species included wheat (Triticumaestivum L.), *herbicide* *resistant* and non-resistant ryegrass (Lolium,spp.), canola (Brassica napus) and lucerne (*Medicago* sativa). Various dilutions were investigated and the original extract was the most effective in inhibiting.....ORGANISMS: *Medicago* sativa (Leguminosae

□ 12/K,6/7 (Item 7 from file: 50)
DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.
0008298120 CAB Accession Number: 20023152089 *Evolution* of paraquat resistance in barley grass (Hordeum leporinumLink. and H. glaucum Steud.).Book Title: 13th Australian *Weeds* Conference: *weeds* "threats now and forever?", Sheraton Perth Hotel, Perth, Western Australia, 8-13September 2002: papers and proceedingsPublication Year: 2002
Herbicide *resistance* in *weed* species can eliminate the usefulnessof herbicides. In Australia, 25 *weed* species have been documented withresistance to one or more of nine herbicide groups. Two *weedy* barleygrass species, H. glaucum and H. leporinum [H. murinum subsp. leporinum],infest crops and...paraquat on these two

species, principally in lucerne and
grain crops,has resulted in the *evolution* of paraquat resistance at a number ofsites in southern Australia. The *evolution* of paraquat resistance occursafter a prolonged period of use, often up to 20 years...
... will lead to a better understanding of how resistance is spread as wellas the *evolution* of paraquat resistance in field populations....DESCRIPTORS: *evolution*; .....*herbicide* *resistance*; .....*weeds*
...*Medicago* sativa...CABICODES: *Weeds* and Noxious Plants (FF500...

□ 12/K,6/8 (Item 8 from file: 50)
DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.
0008751520 CAB Accession Number: 20053008750 *Evolution* and spread of *herbicide* *resistant* barley grass (Hordeumglaucum Steud. and H. leporinum Link.) in South Australia.Book Title: *Weed* management: balancing people, planet, profit. 14thAustralian *Weeds* Conference, Wagga Wagga, New South Wales, Australia,6-9 September 2004: papers and proceedingsPublication Year: 2004 The barley grasses (H. glaucum and H. leporinum (H. murinum subsp.leporinum)) are important *weeds* of crops and pastures in South Australia. Populations of both species have evolved resistance to paraquat, primarily following intensive use of paraquat for winter *weed*
control in lucerne (*Medicago* sativa) crops. In the past few years,agricultural consultants have been reporting an increase in.....This research was conducted to determine the relative importance of seedmovement compared with independent *evolution* for paraquat resistance in
□ Hordeum spp. H. glaucum and H. leporinum seeds were collected from...
... by 7 km appeared to be the same genotype. These results suggest thatboth independent *evolution* and seed movement are important in thedistribution of paraquat-resistant Hordeum spp. in South...DESCRIPTORS: *evolution*; .....*herbicide* *resistance*; .....*weeds*
...*Medicago* sativa...CABICODES: *Weeds* and Noxious Plants (FF500

□ 12/K,6/9 (Item 9 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0008324661
CAB Accession Number: 20023162508
Herbicides in *alfalfa* culture.
Original Title: Herbicidas na cultura da alfafa.
Publication Year: 2002
... the tolerance of lucerne cv. Crioula and the efficiency of

□ pre-emergent herbicides on broadleaved *weed* control, in 2 differentsoils having (a) 0.96% organic matter (OM) and pH of 5.4 and (b) 2.61% OMand pH of 6.1. The *weed* control efficiency of oxyfluorfen and mixture ofdiuron+paraquat was also evaluated one day after...
... 24 and 0.36 of oxyfluorfen. Two controls were added to all experiments,
□ i.e. *weeded* and unweeded. Pre-emergence herbicides were sprayed one dayafter planting in moistened soil. In...
□ ... plants. Oryzalin was selective to the crop, providing a better controlof grasses and broadleaved *weeds* at the 2 highest doses, regardless ofthe amount of OM and soil pH. Acetochlor...
□ ... both contents of OM and soil pH, with excellent control of the broadleaved and grass *weeds*. Flumetsulam and imazaquin may be appliedonly at the lowest dose tested, regardless of OM content in the soil,providing good control of some broadleaved *weeds*, with spraying offluazifop-P-butyl [fluazifop-P] needed in post-emergence. The herbicidesshowed, in average, 10% more control of the *weeds* in soil with 2.61% ofOM and pH of 6.1, in comparison to the *weeds* in the soil with 0.96% ofOM and pH of 5.4. Lucerne budding...
□ .. oxyfluorfen up to 12 days after application; this herbicide presentedgood potential for post-lasting *weed* control and excellent pre-emergencecontrol. Mixture application in tank (diuron+paraquat) just after cutting
... ...DESCRIPTORS: *herbicide* *resistance*; .....*weed* control.....*weeds*...*Medicago* sativa

□ 12/K,6/10 (Item 10 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0009320611 CAB Accession Number: 20073193351

Herbicide-*resistant* crops as *weeds* in North America.
Publication Year: 2007
Growers have rapidly adopted transgenic *herbicide*-*resistant* (HR)

- crops, such as canola (Brassica napus L.), soyabean [Glycine max (L.) Merr.], maize (Zea...crops and subsequent potential for volunteerism of these crops are assessed. HR volunteers are common *weeds* and the relative *weediness*
- depends on species, genotype, seed shatter prior to harvest and disbursement of seed at harvest...limited if the crop volunteers are HR.There are generally no marked changes in volunteer *weed* problemsassociated with these crops, except in no-tillage systems when glyphosate(GLY) is used...

...DESCRIPTORS: *Herbicide* *resistance*; .....*Weed*control.....*Weeds*;
IDENTIFIERS: *alfalfa*; .....*weedicides*; .....*weedkillers*
...ORGANISM DESCRIPTORS: *Medicago* sativa

12/K,6/11 (Item 11 from file: 50)
DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.
0008751696 CAB Accession Number: 20053008458

How profitable are perennial pasture phases in Western Australian cropping systems?
Book Title: *Weed* management: balancing people, planet, profit. 14thAustralian *Weeds* Conference, Wagga Wagga, New South Wales, Australia,6-9 September 2004: papers and proceedings
Publication Year: 2004
... that, in most parts of Western Australia, it is not currentlyprofitable to plant lucerne (*Medicago* sativa) on the scale requiredfor salinity abatement. However, these investigations have not incorporated the long-term benefits that accrue from the use of lucerne toenhance management of *weeds* , especially for those growers facing thethreat or actual presence of *herbicide* *resistance*. This work is an investigation of the economics of lucerne when these various benefits are considered simultaneously. An existing model for analysing *herbicide**resistance* in annual ryegrass (Lolium rigidum) in Western Australia(Ryegrass Resistance and Integrated Management) is extended...
... pasture phase increase long-term profitability, relative to that ofcontinuous cropping, because of improved *weed* management, reduced chemical use and through increasing yields in subsequent cereal crops. Thefirst two benefits help reduce the *evolution* of *herbicide* *resistance* . In addition, the incorporation of lucerne in a rotation can significantly reduce recharge. These results.....DESCRIPTORS: *herbicide* *resistance*; .....*herbicide* *resistant*
weeds; ...
...*weed* control.....*weeds*...*Medicago* sativa

- 12/K,6/12 (Item 12 from file: 55)

DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.
0019917724 BIOSIS NO.: 200700577465
New annual and short-lived perennial pasture legumes for Australianagriculture - 15 years of revolution
2007
ABSTRACT: Fifteen years ago subterranean clover (Trifolium subterraneum)and annual medics (*Medicago* spp.) dominated annual pasture legumesowings in southern Australia, while limited pasture legume options
existed...
...glanduliferum), arrowleaf (Trifolium vesiculosum), eastern star(Trifolium dasyurttm) and crimson (Trifolium incarnatum) clovers andsphere (*Medicago* sphaerocarpos), button (*Medicago* orbicularis) andhybrid disc (*Medicago* tornata x *Medicago* littoralis) medics have beencommercialised. Improved cultivars have also been developed ofsubterranean (T. subterraneum), balansa (Trifolium michelianum), rose(Trifolium hirtum), Persian (Trifolium resupinatum) and purple (Trifoliumpurpureum) clovers, burr (*Medicago* polymorpha), strand (M. littoralis),snail (*Medicago* scutellata) and barrel (*Medicago* 'truncatula) medicsand yellow serradella (Ornithopus compressus). New tropical legumes for
pasture phases in subtropical...likely to increase due to the increasing cost

of inorganic nitrogen, the need to combat *herbicide*-*resistant* crop *weeds* and improved livestock prices. Mixtures of these legumes allows for more robust pastures buffered against...

12/K,6/13 (Item 13 from file: 50)
DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.
0008415606 CAB Accession Number: 20033074295

Preharvest glyphosate in *alfalfa* for seed production: control of Canada thistle. Publication Year: 2003 Canada thistle (Cirsium arvense) is increasing in both frequency and density in Saskatchewan lucerne (*Medicago* sativa) seed fields. Application of preharvest glyphosate is an effective means of controllingCanada thistle...
...DESCRIPTORS: *herbicide* *resistance*; .....*weed* control.....*weeds*...*Medicago* sativa

12/K,6/14 (Item 14 from file: 10)DIALOG(R)File 10:(c) format only 2008 Dialog. All rts. reserv.4818901 44029738 Holding Library: AGL
Role and value of including lucerne (*Medicago* sativa L.) phases in croprotations for the management of *herbicide*-*resistant* Lolium rigidum inWestern Australia
2008 URL: http://dx.doi.org/10.1016/j.cropro.2007.07.018Use of lucerne (*Medicago* sativa L.) pastures in crop rotations has been proposed as a method to enhance *weed* management options for growersfacing *herbicide* *resistance* in Western Australia. An existing model foranalysing *herbicide* *resistance* in the important crop *weed* annualryegrass (Lolium rigidum Gaud.) is consequently extended to include lucerne, used for grazing by...options are analysed, including variouscombinations of lucerne, annual pastures, and crops. Lucerne providesadditional *weed* management benefits across the rotation, but in the region studied these benefits are only sufficient...

12/K,6/15 (Item 15 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.0008983866 CAB Accession Number: 20063055062
Sensitivity of selected crops to isoxaflutole in soil and irrigation water. Publication Year: 2005 ... hectarage crops grown in Michigan, USA. The crops evaluated were: adzuki bean (Vigna angularis), lucerne (*Medicago* sativa), carrot (Daucus carota), cucumber (Cucumis sativus), dry bean (navy and blackbeans; Phaseolus vulgaris...of the rates that resulted in injury were substantially less than the rates used for *weed* control in maize.
Carryover from isoxaflutoleapplications in maize production may require plant back restrictions.....DESCRIPTORS: *herbicide* *resistance*;...*Medicago* sativa

12/K,6/17 (Item 17 from file: 55)DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.17533797 BIOSIS NO.: 200300491454 Tolerance of annual forage legumes to herbicides in Alberta.*2003* ...ABSTRACT: under irrigation. Results indicate that recommended rates of either ethalfluralin or imazethapyr have potential for *weed* control in

alfalfa, berseem clover, balansa clover, fenugreek, pea, and vetches.*alfalfa* (Leguminosae...*herbicide* *tolerance*; ....*weed* controlpotential

12/K,6/18 (Item 18 from file: 50)
DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.
0008566544 CAB Accession Number: 20043017840 *Weed* control in lucerne and pastures
2004.Publication Year: 2003 Information to aid the planning of *weed* control in lucerne and pastures in Australia, is presented under the following headings:
identification of...
...establishing pasture legumes; poison warnings on herbicide labels; usingherbicides successfully; using herbicides in pastures; *weed* glossary;time interval needed between herbicide application and rainfall; *weed*control in seedling lucerne - grass *weeds*; *weed* control in seedlinglucerne - broadleaf *weeds*; *weed* control in established lucerne stands(over one-year-old) -broadleaf *weeds*; *weed* control in establishedlucerne stands (over one-year-old) -grass *weeds*; clover and medic pastures -grass *weeds* -for

presowing, seedling and establishment;clover and medic pastures - broadleaf *weeds* - for presowing, seedlingand established pastures; *weed* control in grass pastures only -broadleaf *weeds*; *herbicide* *resistance* management; direct drill andsurface sowing; perennial grass *weed* control; approximate retail pricesof chemicals used on lucerne and pastures; herbicide volatility; winter crop.....DESCRIPTORS: *herbicide* *resistance*; .....*weed* control.....*weeds* ...*Medicago* sativa

12/K,6/19 (Item 19 from file: 50)DIALOG(R)File 50:(c) 2008 CAB International. All rts. reserv.

0008415608 CAB Accession Number: 20033074293 *Weed* management in irrigated fenugreek grown for forage in rotationwith other annual crops.Publication Year: 2003 ... determine the tolerance of fenugreek (cv. Amber) to several herbicides and their efficacy on various *weeds* (Avena fatua, Setariaviridis and Amaranthus retroflexus) in 1997-99 in Alberta, Canada.Potentially, fenugreek...effect of herbicides, seeding method, and 11 previous crops on fenugreek yield. Without herbicide application, *weeds* contributed 37-86% to total dry matter production. When imazamox/imazethapyr, or combinations of imazamoz/imazethapyr or imazethapyr with ethalfluralin was applied, *weed*contents were 5% of the total dry matter and the herbicides did notreduce fenugreek yield compared to the hand-*weeded* control. Total foragesamples with a low *weed* content had lower fibre content and higherprotein and digestible dry matter content than forages with a high *weed*content. When imazamox/imazethapyr was used for *weed* control, fenugreekyields and *weed* biomass were similar after direct seeding and aftercultivation plus seeding. In addition, the effect... ... and the previous crop by seeding method interaction was not significantfor fenugreek yield and *weed* biomass. Therefore, irrigated fenugreek canbe successfully grown in conservation tillage systems in rotation withseveral crops provided an effective herbicide is used for *weed* control.

...DESCRIPTORS: *herbicide* *resistance*; .....*weed* control...*Medicago*sativa

□ 12/K,6/20 (Item 20 from file: 55)
DIALOG(R)File 55:(c) 2008 The Thomson Corporation. All rts. reserv.
0020265062 BIOSIS NO.: 200800312001
Winter annual *weed* control with herbicides in *alfalfa*-orchardgrass mixtures
2008
4.0 ABSTRACT: *Alfalfa*-orchardgrass hay is popular in the Western UnitedStates because of an expanding horse-hay market. However, *weed* controlin mixed *alfalfa*-orchardgrass stands is problematic, as herbicides mustbe safe for both species. Most growers rely solely on the competitivenessof the crop for *weed* control, which is often insufficient, especiallyin older stands. Field experiments were established in northernCalifornia to determine the efficacy and crop safety of severalherbicides for winter annual *weed* control in established *alfalfa* -orchardgrass. Metribuzin at 560 or 840 g/ha and hexazinone at 420 g/ha applied...
...Paraquat at 560 g/ha applied shortly after crop green-up gave 50 to 82%*weed* control and caused significant injury to orchardgrass, which wasstill noticeable at first cutting....ORGANISMS: *Medicago* sativa {*alfalfa*} (Leguminosae)MISCELLANEOUS TERMS: *herbicide* *tolerance*

1.5 Supplemental Searches

www.scirus.com
Terms:
alfalfa AND glyphosate (40 titles evaluated)

www.scholar.google.com
Terms:
alfalfa AND glyphosate

www.yahoo.com
Terms:
Alfalfa hay
Alfalfa sprouts
Organic alfalfa sprouts
Alfalfa seeds
Alfalfa glyphosate
Feral alfalfa
Wild alfalfa
Alfalfa state extension guidance
Perennial bluegrass
Quackgrass
Red horned poppy
Sprangletop weed
Tall waterhemp
White cockle weed
Butyrac
Butoxone
Benefin
Balan herbicide
Bromoxynil herbicide
Clethodim herbicide
Prism herbicide
Select herbicide
Diuron herbicide
EPTC herbicide
Velpar herbicide
Raptor herbicide
Pursuit herbicide
Sencor herbicide
Solicam herbicide
Paraquat herbicide
Pronamide herbicide
Kerb herbicide
Poast herbicide
Terbacil herbicide
Sinbar herbicide
Trifluralin herbicide
Treflan/TR-10 herbicide

www.google.com
Terms:
alfalfa bloom
alfalfa crop rotation
alfalfa cultivation
alfalfa harvest
alfalfa quality definitions
alfalfa quality standards
alfalfa quality statistics
alfalfa sprouts
alfalfa weeds
dandelion off-taste milk
dairy cows
Eleucine indica
Burdock weed
Certified organic alfalfa seed
Common ragweed
Common ragweed weed problem
Gene flow simulation
GENESYS gene flow
Glyphosate
Glyphosate resistant weeds
Growing regions
Herbicide active ingredients
Horseweed
Lucerne Medicago
Meadow foxtail
Organic alfalfa acres
Organic alfalfa acres USDA
Organic alfalfa certified
Organic alfalfa seeds
Organic alfalfa statistics
Pigweed
Roundup ready label
Tansymustard
Tansyweed
Teuber gene flow alfalfa
Visual definition for alfalfa quality
Weed interference with rhyzobium
Weeds off tasting milk
Weeds taste in milk
Horseweed Italian ryegrass
Italian ryegrass weed
Palmer amaranth
Buckhorn plantain
Goosegrass

Junglerice
Echinochloa junglerice
Burning nettle
Utica uren
Erodium filaree
Purslane weed
Large crabgrass in alfalfa
Bermudagrass weed alfalfa
Large crabgrass weed
Morning glory toxic livestock
Morning glory weed
Nutsedge
Nutsedge toxic livestock
alfalfa stand removal
volunteer alfalfa
alfalfa autotoxicity

Appendix G-3. Weeds in Alfalfa

Table G-9. Weeds in Alfalfa

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
African mustard	*Brassica tournefortii* Asian mustard wild turnip	Broadl eaf	WA								X	Rogan and Fitzpatrick 2004
Barnyardgrass	*Echinochloa crus-galli*, cockspur grass, Japanese millet watergrass cockspur watergrass	Grass	SA	X	X			X	X	X	X	Rogan and Fitzpatrick 2004
Bermudagrass	*Cynodon spp.*	Grass	P			X		X			X	Rogan and Fitzpatrick 2004
Blessed milk thistle	*Silyburn marianum* blessed milkthistle milk thistle spotted thistle variegated thistle	Dicot	A								X	Canevari et al., 2007
Blue mustard	*Chorispora tenella*, beanpodded mustard chorispora crossflower purple mustard tenella mustard	Broadl eaf	WA		X		X					Rogan and Fitzpatrick 2004
Bluegrass (annual)	*Poa annua* walkgrass, annual bluegrass	Grass	WA			X		X			X	Rogan and Fitzpatrick 2004
Bluegrass (perennial)	*Poca* spp. Perennial bluegrass	Broadl eaf	P		X							Rogan and Fitzpatrick 2004
Bristly oxtongue*	*Picris echioides*	Dicot	WA								X	Canevari et al., 2007
Bromes	*Bromus* spp.	Grass	WA								X	Rogan and Fitzpatrick 2004
Buckhorn plantain	*Plantago lanceolata*	Broadl eaf	P					X		X		Rogan and

[25] Source: http://plants.usda.gov/java/invasiveOne.

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	English plantain buckhorn plantain lanceleaf plantain narrowleaf plantain ribgrass ribwort *Plantago major* broadleaf plantain buckhorn plantain common plantain rippleseed plantain											Fitzpatrick 2004
Buffalobur	*Solanum rostratum* Colorado bur Kansas thistle Mexican thistle Texas thistle Buffalobur nightshade	Broadleaf	SA					X				Rogan and Fitzpatrick 2004
Bulbous bluegrass	*Poa bulbosa*	Grass	P							X		Rogan and Fitzpatrick 2004
Bull thistle	*Cirsium lanceolatum*	Broadleaf	P							X		Rogan and Fitzpatrick 2004
Burcucumber	*Sicyos angulatus* Wall bur cucumber	Broadleaf	SA			X						Rogan and Fitzpatrick 2004
Burning nettle	*Urtica dioica* California nettle slender nettle stinging nettle tall nettle	Broadleaf	A								X	Canevari et al., 2004; Canevari et al., 2006b
Bushy wallflower	*Ersimum repandum* Treacle mustard	Broadleaf	WA					X				Rogan and Fitzpatrick 2004
California burclover	*Medicago polymorpha* burclover	Dicot	WA-P								X	Canevari et al., 2007
Canada thistle	*Cirsium arvense* Californian thistle creeping thistle	Broadleaf	P	X	X		X			X		Rogan and Fitzpatrick 2004

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	field thistle Cirsium thistle											
Canarygrass	*Phalaris arundinacea* canary grass reed canarygrass *Phalaris canariensis* canary grass *Phalaris minor* canarygrass littleseed canarygrass	Grass	WA								X	Rogan and Fitzpatrick 2004
Carolina geranium	*Geranium carolinianum*	Broadleaf	WA			X						Rogan and Fitzpatrick 2004
Cheatgrass	*Bromus tectorum* downy brome early chess military grass thatch bromegrass	Grass	WA	X	X		X	X	X	X	X	Rogan and Fitzpatrick 2004
Cheeseweed	*Malva neglecta* buttonweed cheeseplant little mallow common mallow	Broadleaf	WA-P							X	X	Rogan and Fitzpatrick 2004
Chickweed (common)	*Stellaria media*	Broadleaf	WA	X	X	X		X	X			Rogan and Fitzpatrick 2004
Chicory	*Cichorium intybus* blue sailors chicory coffeeweed succory	Broadleaf	P							X		Rogan and Fitzpatrick 2004
Coastal fiddleneck	*Amsinckia menziesii* var. *intermedia* coast buckthorn coast fiddleneck common fiddleneck fiddleneck	Broadleaf	WA							X		Rogan and Fitzpatrick 2004
Cocklebur (common)	*Xanthium strumarium* cocklebur common cocklebur rough cocklebur	Broadleaf	SA	X	X	X			X			Rogan and Fitzpatrick 2004
Cornflower	*Centaurea cyanus*	Broadleaf	WA			X						Rogan and

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	bachelor's button garden cornflower											Fitzpatrick 2004
Crabgrass	*Digitaria bicornis* Asian crabgrass *Digitaria ciliaris* Henry's crabgrass fingergrass kukaepua'a saulangi smooth crabgrass tropical crabgrass *Digitaria ischaemum* small crabgrass smooth crabgrass *Digitaria Sanguinalis* hairy crabgrass large crabgrass purple crabgrass	Grass	SA	X	X	X		X				Rogan and Fitzpatrick 2004
Creeping swinecress	*Coronopus didymus* lesser swinecress *Coronopus squamatus* creeping wartcress swinecress	Dicot	WA								X	Canevari et al., 2007
Cupgrasses	*Eriochloa gracilis* southwestern cupgrass tapertip Cupgrass *Eriochloa contracta* prairie cupgrass *Eriochloa villosa* woolly cupgrass	Grass	SA					X			X	Rogan and Fitzpatrick 2004
Curly dock	*Rumex crispus* narrowleaf dock sour dock yellow dock Rumex dock	Broadleaf	P	X	X	X		X				Rogan and Fitzpatrick 2004
Cutleaf	*Oenothera*	Broadl	WA					X				Rogan

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
eveningprimrose	*laciniata* cut-leaved evening primrose	eaf										and Fitzpatrick 2004
Dallisgrass	*Paspalum dilatatum* dallies grass herbe de miel herbe sirop hiku nua palpalum dilate water grass	Grass	P								X	Canevari et al., 2007
Dandelion (common)	*Taraxacum officinale* blowball common dandelion faceclock	Broadl eaf	P	X	X		X	X		X		Rogan and Fitzpatrick 2004
Dodder	*Cuscuta* 50 common names for species in the genus	Broadl eaf	SA					X	X	X	X	Rogan and Fitzpatrick 2004
Fall panicum	*Panicum dichotomiforum* western witchgrass	Grass	SA	X		X						Rogan and Fitzpatrick 2004
Fescue	*Festuca* spp. 66 common names for species in the genus	Grass	P			X				X		Rogan and Fitzpatrick 2004
Fescue (tall)	*Festuca arundinacea* *Festuca pratensis* Alta fescue coarse fescue reed fescue tall fescue	Grass	SA							X		Rogan and Fitzpatrick 2004
Field bindweed	*Convolvulus arvensis* creeping jenny European bindweed morningglory perennial morningglory smallflowered morningglory	Broadl eaf	P	X			X					Rogan and Fitzpatrick 2004
Field pepperweed	*Lepidium campestre*	Dicot	WA				X			X		Orloff et al., 1997
Flixweed	*Descurainia sophia*	Broadl eaf	WA				X	X		X		Rogan and

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	flixweed pinnate tansymustard											Fitzpatrick 2004
Foxtail (giant)	*Setaria faberi* Chinese foxtail Chinese millet giant bristlegrass giant foxtail nodding foxtail	Grass	SA	X	X	X		X	X			Rogan and Fitzpatrick 2004
Foxtail (green)	*Setaria viridis* bottle grass green bristlegrass green foxtail green millet pigeongrass wild millet	Grass	SA	X	X	X	X	X	X	X		Rogan and Fitzpatrick 2004
Foxtail (yellow)	*Setaria glauca* pearl millet pigeongrass wild millet yellow bristlegrass yellow foxtail	Grass	SA	X	X	X	X	X	X			Rogan and Fitzpatrick 2004
Foxtail barley	*Hordeum jubatum*	Grass	P				X			X		Rogan and Fitzpatrick 2004
Goosegrass	*Eleusine indica* crowsfoot grass Indian goosegrass manienie ali'i silver crabgrass wiregrass	Grass	SA			X		X				Rogan and Fitzpatrick 2004
Groundsel (common)	*Senecio vulgaris* ragwort old-man-in-the-Spring	Dicot	WA								X	Canevari et al., 2007
Hairy nightshade	*Solanum sarrachoides* hairy nightshade hoe nightshade	Broadleaf	SA							X		Rogan and Fitzpatrick 2004
Hare barley	*Hordeum leporinum* hare barley leporinum barley wild barley	Dicot	WA				X			X	X	Orloff et al., 1997
Henbit	*Lamium amplexicaule* deadnettle	Broadleaf	WA	X	X	X		X		X		Rogan and Fitzpatrick 2004

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
Hoary alyssum	*Berteroa incana* hoary false alyssum hoary false madwort	Broadl eaf	P		X							Rogan and Fitzpatrick 2004
Hoary alyssum	*Berteroa incana* hoary false alyssum hoary false madwort	Broadl eaf	SA	X								Rogan and Fitzpatrick 2004
Horseweed	*Conyza canadeniss* horseweed fleabane mares tail fleabane	Broadl eaf	SA/WA					X				Rogan and Fitzpatrick 2004
Japanese brome	*Bromus japonicus* Japanese bromegrass Japanese chess	Grass	WA					X				Rogan and Fitzpatrick 2004
Jimsonweed	*Datura stramonium* Jamestown weed mad apple moonflower stinkwort thorn apple	Broadl eaf	SA	X		X						Rogan and Fitzpatrick 2004
Johnsongrass	*Sorghum halepense* aleppo milletgrass herbe de cuba sorgho d' Alep sorgo de alepo zacate johnson	Grass	P			X		X				Rogan and Fitzpatrick 2004
Jointed goatgrass	*Aegilops cylindrical* jointgrass	Grass	P					X				Rogan and Fitzpatrick 2004
Junglerice	*Echinochloa colona* junglerice watergrass	Grass	SA								X	Rogan and Fitzpatrick 2004
Kentucky bluegrass	*Poa prantensis*	Grass	P							X		Rogan and Fitzpatrick 2004
Knawel	*Sclerantus annus* German knotgrass	Broadl eaf	WA			X						Rogan and Fitzpatrick 2004
Knotweed	*Polygonum arenastrum*	Broadl eaf	SA						X		X	Rogan and

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	common knotweed doorweed matweed ovalleaf knotweed prostrate knotweed											Fitzpatrick 2004
Kochia	*Kochia scoparia* Mexican burningbush Mexican fireweed fireweed mock cypress summer cypress	Broadleaf	SA		X			X	X			Rogan and Fitzpatrick 2004
Lambsquarters (common)	*Chenopodium album* Lambsquarters White goosefoot	Broadleaf	SA	X	X	X	X	X	X	X	X	Rogan and Fitzpatrick 2004
Little barley	*Hordeum pusillum* little wildbarley	Grass	WA					X				Rogan and Fitzpatrick 2004
London rocket	*Sisymbrium irio*	Grass	WA								X	Rogan and Fitzpatrick 2004
Meadow foxtail*	*Alopecurus pratensis*	Grass	P							X		Rogan and Fitzpatrick 2004
Mexican sprangletop	*Leptochloa uninervia*	Grass	SA								X	Rogan and Fitzpatrick 2004
Mexican tea	*Chenopodium ambrosioides*	Dicot	P								X	Canevari et al., 2007
Miner's lettuce	*Claytonia perfoliata*	Dicot	WA-P								X	Canevari et al., 2007
Morningglory	*Ipomoea* spp.	Broadleaf	SA			X						Rogan and Fitzpatrick 2004
Muhly	*Muhlenbergia frondosa* wirestern muhly *Muhlenbergia racemosa* green muhly marsh muhly	Grass	P							X		Rogan and Fitzpatrick 2004
Musk thistle	*Caruus nutans*	Broadl	WA					X				Rogan

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	Nodding plumeless thistle chardon penche nodding thistle plumeless thistle	eaf										and Fitzpatrick 2004
Mustards	*Brassica* spp.	Broadl eaf	WA			X	X					Rogan and Fitzpatrick 2004
Mustards	*Brassica* spp.	Broadl eaf	SA			X						Rogan and Fitzpatrick 2004
Nettleleaf goosefoot	*Chenopodium murale*	Broadl eaf	SA								X	Rogan and Fitzpatrick 2004
Night-flowering catchfly	*Silene noctiflora* nightflowering silene sticky cockle	Broadl eaf	WA		X							Rogan and Fitzpatrick 2004
Nightshade	*Solanum sarrachoides* hairy nightshade hoe nightshade	Broadl eaf	SA			X			X			Rogan and Fitzpatrick 2004
Nightshade (E. black)	*Solanum ptychanthum* Eastern black nightshade black nightshade	Broadl eaf	SA	X	X							Rogan and Fitzpatrick 2004
Nutsedge (yellow)	*Cyperus esculentus* yellow nutgrass yellow nutsedge	Grass	P	X								Rogan and Fitzpatrick 2004
Nutsedges	*Cyperus esculentus* yellow nutgrass yellow nutsedge *Cyperus rotundus* chaguan humatag cocograss kili'o'opu nutgrass pakopako purple nutsedge	Grass	P								X	Rogan and Fitzpatrick 2004
Palmer amaranth	*Amaranthus palmeri* carelessweed (type of pigweed)	Broadl eaf	SA					X				Rogan and Fitzpatrick 2004
Pennycress	*Thlaspi arvense* Frenchweed	Broadl eaf	WA	X	X				X			Rogan and

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	Fanweed field pennycress pennycress stinkweed											Fitzpatrick 2004
Pepperweeds	*Lepidium densiflorum* common pepperweed greenflower pepperweed peppergrass	Broadleaf	WA					X		X		Rogan and Fitzpatrick 2004
Persian speedwell	*Veronica persica* birdeye speedwell winter speedwell	Broadleaf	WA							X		Rogan and Fitzpatrick 2004
Pigweed spp.	*Amaranthus* spp. redroot pigweed smooth pigweed Powell amaranth spiny amaranth tumble pigweed prostrate pigweed common waterhemp tall waterhemp Palmer amaranth	Broadleaf	SA	X	X	X	X	X	X	X	X	Rogan and Fitzpatrick 2004
Plains coreopsis	*Coreopsis tinctoria* golden tickseed	Broadleaf	WA					X				Rogan and Fitzpatrick 2004
Plantains	*Plantago major* common plantain broadleaf plantain buckhorn plantain rippleseed plantain	Broadleaf	P			X		X				Rogan and Fitzpatrick 2004
Poverty sumpweed	*Iva axillaris* Iva poverty weed Lesser marshelder mouseear povertyweed poverty sumpweed poverty weed smallflowered marshelder	Broadleaf	P							X		Rogan and Fitzpatrick 2004
Prickly lettuce	*Lactuca serriola* China lettuce	Broadleaf	WA					X	X	X		Rogan and

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	wild lettuce											Fitzpatrick 2004
Purslane	*Portulaca oleracea* akulikuli-kula common purslance duckweed parsley pusley wild portulaca	Broadl eaf	SA						X			Rogan and Fitzpatrick 2004
Quackgrass	*Elytrigia repens* couchgrass quackgrass quickgrass quitch scutch twitch *Elymus repens* couchgrass dog grass	Grass	P	X	X				X	X		Rogan and Fitzpatrick 2004
Rabbitsfoot grass	*Polypogon monspelienisis* rabbitfoot polypogon rabbitfootgrass	Grass	WA								X	Rogan and Fitzpatrick 2004
Ragweed (common)	*Ambrosia artemisiifolia* Roman wormwood annual ragweed common ragweed low ragweed short ragweed small ragweed	Broadl eaf	SA	X	X	X		X				Rogan and Fitzpatrick 2004
Red horned poppy*	*Glausium carniculatum*	Broadl eaf	WA					X				Rogan and Fitzpatrick 2004
Red sprangletop*	*Leptochloa filiformis*	Grass	SA								X	Rogan and Fitzpatrick 2004
Redstem filaree	*Erodium cicutarium* redstem stork's bill alfilaree filaree stork's bill	Broadl eaf	WA							X		Rogan and Fitzpatrick 2004
Rescuegrass	*Bromus catharticus* rescue brome	Grass	WA					X				Rogan and Fitzpatrick

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
												2004
Roughseed buttercup*	*Ranunculus muricatus*	Dicot	WA-P								X	Canevari et al., 2007
Russian thistle	*Salsola kali* tumbleweed *Salsola iberica* prickly Russian thistle tumbleweed tumbling thistle	Broadleaf	SA		X			X	X	X		Rogan and Fitzpatrick 2004
Ryegrass	*Lolium multiforum* Italian ryegrass annual ryegrass	Grass	WA			X				X		Rogan and Fitzpatrick 2004
Ryegrass (perennial)	*Lolium perenne* Perennial ryegrass	Grass	WA							X		Rogan and Fitzpatrick 2004
Sandbur	*Cenchrus echinatus* burgrass common sandbur field sandbur konpeito-gusa se mbulabula vao tui tui	Grass	SA					X	X			Rogan and Fitzpatrick 2004
Shepardspurse	*Capsella bursa-pastoris* Shephardspurse	Broadleaf	WA	X	X	X	X	X	X	X	X	Rogan and Fitzpatrick 2004
Silversheath knotweed*	*Polygonum argyrocoleon*	Broadleaf	WA								X	Rogan and Fitzpatrick 2004
Smartweed	*Polygonum persicaria* lady's thumb ladysthumb smartweed	Broadleaf	SA	X	X	X						Rogan and Fitzpatrick 2004
Sowthistle	*Sonchus* spp. (5 species)	Broadleaf	P						X			Rogan and Fitzpatrick 2004
Spiny sowthistle	*Sonchus asper* perennial sowthistle prickly sowthistle	Broadleag	WA					X				Rogan and Fitzpatrick 2004
Sprangletops	*Leptochloa fascicularis* bearded sprangletop	Grass	SA					X				Rogan and Fitzpatrick 2004

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	Also other *leptochloa*											
Squirreltail*	*Sitanion hystrix*	Grass	P							X		Rogan and Fitzpatrick 2004
Stinkgrass	*Eragrostis cilianensis* candy grass lovegrass strongscented lovegrass	Grass	SA							X		Rogan and Fitzpatrick 2004
Sunflower (common)	*Helianthus annuus* annual sunflower common sunflower sunflower wild sunflower	Broadleaf	SA				X		X	X		Rogan and Fitzpatrick 2004
Swamp knotweed*	*Polygonum coccineum*	Broadleaf	P							X		Rogan and Fitzpatrick 2004
Tall waterhemp	*Amaranthus tuberculatus* roughfruit amaranth tall waterhemp	Broadleaf	SA		X			X				Rogan and Fitzpatrick 2004
Tansy mustard	*Descurainia pinnata* green tansymustard tansymustard	Broadleaf	SA		X			X	X	X		Rogan and Fitzpatrick 2004
Toad rush	*Juncus bufonius*	Grass	WA								X	Canevari et al., 2007
Tumble mustard	*Sisymbrium altissimum* Jim hill mustard tall mustard tumble mustard tumbleweed mustard	Broadleaf	SA						X	X	X	Rogan and Fitzpatrick 2004
Velvetleaf	*Abutilon theophrasti* Indian mallow butterprint buttonweed	Broadleaf	SA	X	X	X						Rogan and Fitzpatrick 2004
Virginia pepperweed	*Lepidium virginicum* Virginia Pepperweed Virginia	Broadleaf	WA			X						Rogan and Fitzpatrick 2004

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
	peppercress peppergrass poorman's pepper											
Volunteer grains		Grass	WA-SA	X		X		X	X	X		Rogan and Fitzpatrick 2004
White cockle	*Silene latifolia* bladder campion evening lychnis white campion	Broadleaf	P		X							Rogan and Fitzpatrick 2004
Wild celery*	*Apium graveolens*	Dicot	SA-P								X	Canevari et al., 2007
Wild mustard	*Brassica arvensis* wild mustard *Brassica kaber* canola charlock mustard kaber mustard rapeseed wild mustard	Broadleaf	SA	X	X				X			Rogan and Fitzpatrick 2004
Wild oats	*Avena fatua* flaxgrass oatgrass wheat oats	Grass	SA-WA		X				X	X	X	Rogan and Fitzpatrick 2004
Wild radish	*Raphanus raphanistrum*	Broadleaf	SA	X	X	X						Rogan and Fitzpatrick 2004
Windmillgrass	*Chloris verticillata* tumble windmill grass windmillgrass	Grass	P					X				Rogan and Fitzpatrick 2004
Witchgrass	*Panicum capillare* panicgrass ticklegrass tumble panic tumbleweed grass witches hair	Grass	SA	X						X		Rogan and Fitzpatrick 2004
Yellow rocket	*Barbarea vulgaris* garden yellow rocket winter cress	Broadleaf	P	X	X							Rogan and Fitzpatrick 2004
Yellow starthistle	*Cantaurea solstitialis*	Dicot	WA				X			X		Canevari et al., 2007

Common Name	Scientific Name and Synonyms[25]	Type	Season	East Central	North Central	Southeast	Winter Hardy Inter-mountain	Great Plains	PNW	Moderate Inter-mountain	Southwest	Source
Yellowflower pepperweed	*Lepidium perfoliatum* clasping pepperweed	Dicot	WA				X			X		Orloff et al., 1997

Appendix F

Selected Comments to Draft Environmental Impact Statement form Farmers Using Roundup Ready Alfalfa

APHIS-2007-0044-0320

Name: Daniel M. Luckwaldt
Address: Woodville, WI

Submitter's Representative: Daniel Luckwaldt
Organization: Luckwaldt Agriculture Inc.

I am a dairy farmer who planted 100 acres of round-up ready alfalfa when it was available. I seemed to work very good. Additionally it allowed me to plant my alfalfa in a no-till manner (which leaves a smaller carbon footprint) and not worry about weeds. Seemed like it was the best alfalfa I ever grew and was very easy/simple to manage.

APHIS-2007-0044-0516.1

Name: Gene Robben
Address: Dixon, CA

Organization: Robben Ranch

Robben Ranch is a large farming operation located near the town of Dixon, California. This farming operation normally raises approximately 4,000 acres of alfalfa each year. The hay that is produced on this ranch supplies several dairy and cattle operations in the southern part of the Sacramento valley and the northern part of the San Joaquin valley. Each fall this ranch tries to replace older stands of alfalfa and replaces fields of alfalfa that are of poor quality. These fall plantings can range from 800 to 1,000 acres. Fall planting of alfalfa has been the most successful for Robben Ranch.

Three years ago, Robben Ranch planted 600 acres of Roundup Ready Alfalfa to see how this new variety would produce and what type of quality it would have. This fall was the third year of production for the new Roundup Ready variety. It was found from production records that the Roundup Read Alfalfa equaled other varieties in production per acre, and had outstanding tests in T.D.N. (total digestible nutrients). The other factor that was a concern was how resistant was this alfalfa to Roundup Herbicide. After a few Roundup sprays, there was no apparent loss of plants or stands over the three year period.

Many farmers know that with our standard varieties of alfalfa, w can spend form $50 - $100 per acre annually for weed control. With Roundup Ready Alfalfa, expenses range from $10 - $30 per acre per year, which is a considerable savings over standard weed control. It was also noticeable that in the Roundup Ready Alfalfa fields almost 100% weed control was obtained.

Robben Ranch hopes the government will release Roundup Ready Alfalfa seed for the 2010 planting season. If so, this ranch will probable plant 1,000 acres of Roundup Ready Alfalfa this coming fall season. I feel that the government regulators fully analyze the benefit that Roundup Ready Alfalfa has for the American farmer and the environment they will release the seed for sale.

From an environmental standpoint, one can only hope that the regulators will find that with the release of Roundup Ready Alfalfa seed, several million pounds of current herbicides will be greatly decrease or eliminated. Velpar, Sincor, Direx, Gramoxone, and Treflan TR-10 granules

are just a few examples of these current herbicides being used. With the reduction of these herbicides, our streams and waterways will be much safer for our environment and us.

Document: APHIS-2007-0044-0813

Name: Kurt Robert Brink
Address: Richview, IL

Biotechnology-based breeding methods safely enhance and extend a crop's yield potential, feed value, adaptation, pest tolerance, environmental benefits, crop management and utilization options, as other biotech crops have demonstrated. The Roundup Ready alfalfa system provides dependable, cost-effective control of broadleaf and grassy weeds for the life of the alfalfa stand.
I have had a plot of RR Alfalfa now for at least 3 years and it has proven to be a major plus for our Dairy business in that we usually are able to maintain at least a RFV of 155 or better in each of 5 cuttings/year. With the ability to control weed growth, it is one of, if not the best stand I have among the 4 fields I do have in alfalfa.
It is imperative in these tough economic times that we are not deprived of whatever advantage we can glean from the seed technology this variety provides.Roundup Ready alfalfa can lead to more consistent, high-quality, weed-free hay, resulting in an increased supply of dairy-quality hay. The forage produced from Roundup Ready alfalfa is comparable in composition, nutritional value and safety to that produced from conventional alfalfa varieties, resulting in proven feed safety. Dairy farmers can benefit from increased milk production per ton of feed and fewer animals sickened by weeds in their feed.
I urge the USDA to consider biotechnology's long history of success and allow alfalfa growers to join other American farmers in the benefits and new opportunities offered by biotechnology.

Kurt Brink
B&B Dairy Farms
Illinois

Document: APHIS-2007-0044-1094
Comment from John Maddox

Name: John Maddox
Address: Burrell, CA

I am a dairyman and alfalfa grower. I currently grow 2,400acs of conventional alfalfa and I would like to have the ability to purchase and grow Roundup Ready alfalfa. I did grow 40acs of Roundup Ready alfalfa when it was first avialable and was extremely satisfied with it.
The Roundup Ready system is extremely effective in controlling some of our toughest weeds that we have in our hay fields especially nutgrass which is a big problem for us to control with the currently avialable products that we have.
It eliminates summer grasses in the alfalfa which gives me greater flexibility in my winter spray applications.
I firmly believe that if I am able to grow Roundup Ready alfalfa, I am going to be able to better protect my workers because they will not have to be exposed to the more toxic herbicides that I currently have to use to control my weeds. This is a huge issue for us in California especially

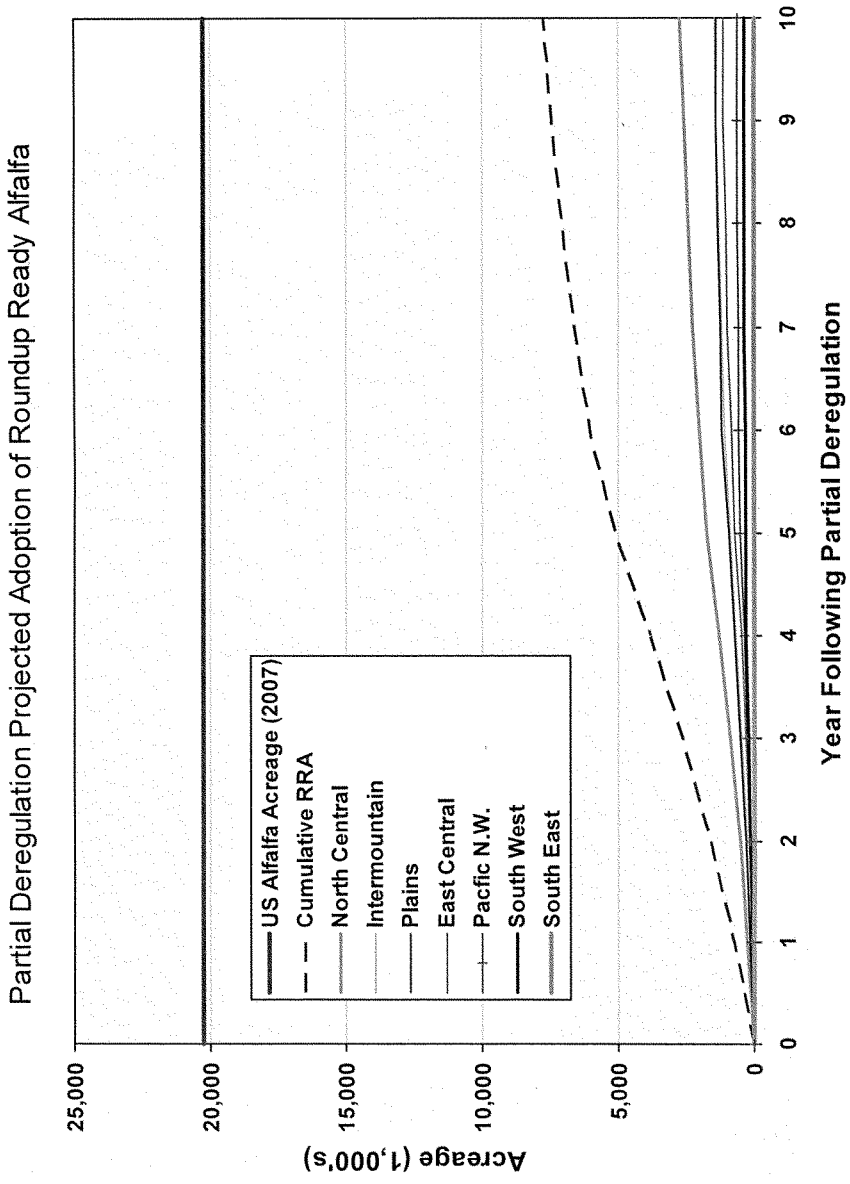
with the many worker safety regulations that we put in place to provide a safe work environment for our employees.
For our dairy, it is of high importance to us to provide the highest quality feed that we can find for our milk cows so that we can maximize their production of high quality milk and butterfat. By growing Roundup Ready alfalfa, I found that my alfalfa was higher in quality and tonnage per acre due to the fact that it was much cleaner than my conventional fields. My 40acres of Roundup Ready alfalfa was the first field that ever produced 10 tons/acre for the year. We have never been able to do that with our conventional varities. This higher production per acre allows me to use less alfalfa acres to provide me the same amount of hay that I currently get from my conventional fields. This frees up some ground for me to rotate into other crops.

Third, because herbicide resistance is a heritable trait, it takes multiple growing seasons for herbicide tolerant weeds to emerge and become the predominant biotype in a specific area (Cole, 2010a, p. 4). Researchers have concluded that even if growers completely relied on only one herbicide, it is likely to take at least five years for an herbicide-resistant weed population to develop (Kniss, 2010a, p4; Beckie 2006, Neve, 2008; Werth et al., 2008). This is a reason why crop monitoring and follow up by University and industry weed scientists in cases of suspected resistance are important parts of all herbicide resistance stewardship programs.

The practice of repeated, in-season mowing combined with alfalfa's perennial nature reduce the likelihood of glyphosate-resistant weed development in >99 percent of the crop's acreage. The ability for alfalfa to fix nitrogen encourages the decision to follow alfalfa in the rotation with a crop that requires additional nitrogen, such as the annual grasses of corn and various cereal crops. These subsequently rotated crops can tolerate a spectrum of herbicides substantially different from the herbicides used in alfalfa. This encourages rotation of crops and herbicides, both of which are highly recommended for reducing the probability of developing herbicide resistant weeds (Orloff et al., 2009; USDA APHIS, 2009, P. 109).

Appendix G

Chart of Anticipated Adoption of RRA Under Partial Deregulation, Prepared by Monsanto/FGI (August 4, 2010)


Partial Deregulation Projected Adoption of Roundup Ready Alfalfa
Acreage (1,000's)
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
9
10
Year Following Partial Deregulation
US Alfalfa Acreage (2007)
Cumulative RRA
North Central
Intermountain
Plains
East Central
Pacific N.W.
South West
South East

Appendix H

Roundup Ready Alfalfa Satisfaction Study
(Study #091 113 1108)
Prepared by Market Probe, Inc., December 2008

MONSANTO imagine™

ROUNDUP READY ALFALFA SATISFACTION STUDY

(Study #091 113 1108)

Prepared By:

MARKET PROBE, INC.

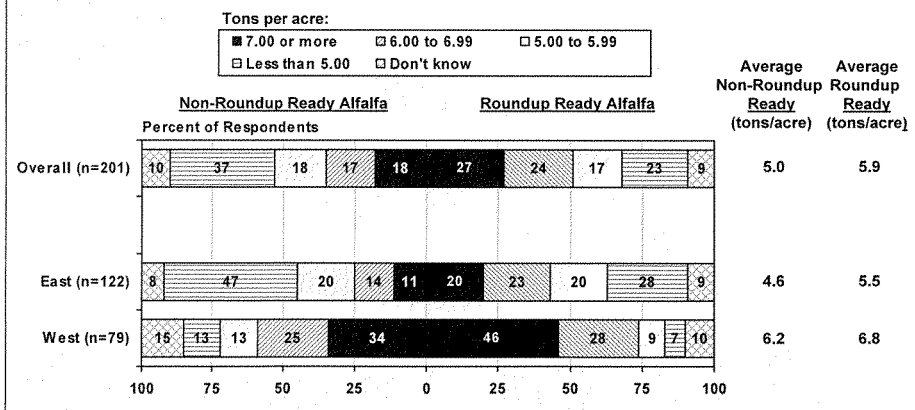
St. Louis, Missouri

December 2008

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Yields On Established Roundup Ready Acres Compared To Established Or Past Non-Roundup Ready Acres

[Base=All respondents]



	Average Non-Roundup Ready (tons/acre)	Average Roundup Ready (tons/acre)
Overall (n=201)	5.0	5.9
East (n=122)	4.6	5.5
West (n=79)	6.2	6.8

Q.8b In terms of tons per acre, what was the annual yield on [Established Roundup Ready alfalfa acres][Established non-Roundup Ready alfalfa acres]?

Appendix I

Putnam, D. and D. Undersander. 2009. Understanding Roundup Ready Alfalfa (Full Version). Originally Posted on the Hay and Forage Grower Magazine Web Site at: http://hayandforage.com/understanding_roundup_ready_alfalfa_revised.pdf (January 1, 2009)

Appendix I
Putnam and Undersander (2009)

Pages 1-3 of Appendix I:

Magazine Version

Holin, F. 2009. Roundup Ready Reality? (Partial version of Putnam and Undersander. 2009. Available at: http://license.icopyright.net/user/viewFreeUse.act?fuid=OTQxOTg4Mg%3D%3D (August 3, 2010)

Pages 4-6 of Appendix I:

Full Version

Putnam, D. and D. Undersander. 2009. Understanding Roundup Ready Alfalfa (full version). Originally posted on the Hay and Forage Grower Magazine web site at: http://hayandforage.com/understanding_roundup_ready_alfalfa_revised.pdf (January 1, 2009).



Hay & Forage GROWER

January 1, 2009

Roundup Ready Reality?

by Fae Holin

Is emotion trumping science in debates over the release of Roundup Ready alfalfa? Two forage specialists think so. They've put together a paper debunking what they call misinformation presented at annual conferences around the country.

"We want to dispel some of those myths," says Dan Undersander, University of Wisconsin extension forage specialist. Undersander and his colleague at University of California-Davis, Dan Putnam, offer "a scientific perspective" for alfalfa growers and industry representatives as they evaluate Roundup Ready (RR) alfalfa.

RR alfalfa, legalized in 2005, lost that designation with a court injunction just about two years later. A USDA environmental impact statement, required by the court, is nearing completion with a public comment period expected in the next month. A decision on whether the transgenic crop should again be made available to growers is expected to follow several months later.

In the meantime, the forage specialists want to make sure the alfalfa industry is well-informed. They've offered *Hay & Forage Grower* a preview of their paper, which will be published in its entirety at hayandforage.com [http://hayandforage.com/understanding_roundup_ready_alfalfa_revised.pdf].

Here's a synopsis of their concerns:

1. Once you release this gene, you can't call it back.

Undersander and Putnam respond that the gene is already out - more than 300,000 acres of RR alfalfa have been planted for hay and a limited amount planted for seed. The real question, they write, is whether growers can continue to plant conventional seed. Their answer: Only non-RR alfalfa is being planted now and, if concerned about contamination, growers can test it for the RR gene.

2. Won't contamination from neighboring fields result in all seed being Roundup Ready eventually?

"No," they emphasize, citing that seed production methods and isolation distances will keep the presence of the gene "at a very low level for seed" and that "non-genetically enhanced (non-GE) seed will always be available."

3. Won't my neighbor's RR hayfields contaminate my non-GE alfalfa hay production through pollen and gene flow?

"No," they write. "There is an extremely low probability of gene flow among hayfields. For this to happen, fields must flower at the same time, pollinators must be present to move pollen (it does not blow in wind), plants must remain in fields four to six weeks after flowering for viable seed production, seed must shatter to fall to the ground and establish on the soil surface, seedlings must overcome autotoxicity to germinate and seedlings must overcome competition from existing plants."

Pollen can only be carried by pollinators such as bees, and honey bees don't like to pollinate alfalfa, they add. The specialists discuss the difficulties of the seed germinating, concluding that if growers take care to plant non-RR seed, it's unlikely their hayfields will become contaminated with the gene.

4. Will the seed companies be able to keep seed from being contaminated?

"Yes. The greatest real potential for pollen flow and contamination is during seed production," Undersander and Putnam write. They cite ways the seed industry has agreed to keep track of transgenic seed and reasons why it's in the companies' best interests to do so.

5. Won't feral alfalfa be a source of contamination?

"Feral (wild growing) alfalfa can act as a bridge for moving genes from one seed field to another, and thus should be controlled to prevent gene flow in any area where seed production occurs, whether GE or not. Feral alfalfa is primarily an issue in portions of Western states because little occurs elsewhere," write the forage specialists. They discuss reasons why feral seed would have low production and suggest that removing plants from ditches and roads is a good idea to prevent gene flow.

6. Won't hard seed be a source of contamination?

"Hard seed of alfalfa generally does not persist for more than one year in moist soils, much less after years of hay production," they respond. "To guard against hard seed carryover, seed growers take steps to eliminate residual alfalfa volunteers prior to planting. State seed certification standards already require that the alfalfa seed field's history include a two-year exclusion period before planting alfalfa for seed."

7. Much of the hay in my area is cut late with mature seed - we have good farmers but weather and equipment problems force late cuttings.

"This occasionally happens," Putnam and Undersander answer. "However, plants must remain in a field for four to six weeks after pollination of flowers for viable seed to form and longer for seed to shatter." Delayed cutting will cause little to no seed production in hayfields, and hay harvest should remove seed.

The last seven concerns have to do with **8)** growing organic hay; **9)** export markets; **10)** whether seed companies bias the research on RR alfalfa; **11)** possible effects it may have on insects, animals or the environment; **12)** whether farmers can or will follow stewardship protocols; **13)** weed resistance to Roundup and **14)** whether the risks of RR alfalfa outweigh the rewards.

"There is also a risk with NOT moving ahead with a technology," Under-sander and Putnam contend. RR alfalfa will control tough weeds, they write. "Further, if this breeding methodology is permanently banned, it would mean fewer genetic advancements for alfalfa in the future.

"It is important that alfalfa growers and the industry understand how to use this important new genetic tool, while at the same time, protecting those farmers who don't wish to adopt it."



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Authors: Dan Putnam, University of California, and Dan Undersander, Univeristy of Wisconsin
January 2009

Understanding Roundup Ready Alfalfa

A number of concerns have been raised about the release of Roundup Ready (RR) alfalfa, the first biotech trait in alfalfa. Many of these concerns have been fueled by misinformation. In this article, we provide a scientific perspective on these concerns that we hope will inform.

Concern 1. Once you release this gene – you can't call it back.

Over 300,000 acres of RR alfalfa have been planted for hay over the past 2 to 3 years, with a limited amount planted for seed. The real question is whether you can continue to plant conventional alfalfa seed and the answer is a resounding 'yes' – all of the seed currently for sale is 'conventional' – and you only need to test it (or ask the seed company to test it) with inexpensive test strips to make sure it does not contain the gene if you don't want it. Conventional alfalfa seed will continue to be available after Roundup Ready alfalfa is released.

Concern 2. Won't contamination from neighboring fields result in all seed being Roundup Ready, eventually?

No. Seed production methods and isolation distances currently recommended by seed companies should keep adventitious presence at a very low level for seed. A gene will increase in a population only if the new gene gives the plant an advantage over other plants and the conditions creating the advantage are consistently present. Conversely, if plants are grown in an environment where the gene provides no advantage, the gene is more likely to remain in the population at very low levels or to be lost from the population. The formulas for computing these changes in gene frequency can be found in most books on population or quantitative genetics, such as Falconer and MacKay, 1996, Introduction to Quantitative Genetics, Longman Press. Thus non-GE seed will always be available.

Concern 3. Won't my neighbor's Roundup Ready hay fields contaminate my conventional or organic alfalfa hay production through pollen and gene flow?

No. There is almost zero probability of gene flow among hay fields. For this to happen all the following must occur:

- fields must flower at same time.
- pollinators must be present to move pollen (it does not blow in wind).
- plants must remain in field 4 to 6 weeks after flowering for viable seed production.
- seed must shatter, to fall to ground and establish on soil surface.
- seedlings must to overcome autotoxicity to germinate.
- seedlings must to overcome competition from existing plants.

Pollen moves among alfalfa plants only when carried by pollinators such as bees, and honey bees do not like to pollinate alfalfa. Alfalfa seed takes many weeks after flowering to mature sufficiently to germinate and longer to shatter and fall onto the ground. Alfalfa seed does not readily spread. Alfalfa does not germinate well on the soil surface. Germination will be further reduced by alfalfa autotoxicity from existing planting in the hay field (this is why interseeding alfalfa to thicken a stand generally fails). Germinating seeds must compete with established plants for water, nutrients and sunlight. Data has shown that interseeded plants generally die during the first growing season. Thus, if a grower takes care to plant conventional seed, it is very unlikely that the Roundup Ready gene will move to their hay fields. (See Gene Flow in Alfalfa: Biology, Mitigation, and Potential Impact on Production, Special Publication of the Council for Agricultural Science and Technology (CAST) at http://www.cast-science.org/displayProductDetails.asp?idProduct=157)

Concern 4. Will the seed companies be able to keep seed from being contaminated?

Yes, the greatest real potential for pollen flow and contamination is during seed production. The seed industry has agreed on a field tagging technique in areas where RR alfalfa seed will be grown so neighbors and other seed companies will know where RR seed is being produced. The bulk of non-GE alfalfa seed is produced for export by seed production companies and it is in their own best interest to control seed production to continue to produce the 30% or more of total production as non-biotech for export. This large volume of export seed production is much more significant economically than the less than 1% of total seed market for organic seed production. However, concerns and methodology for exported seed will allow organic seed production indefinitely, making non-biotech seed available to growers.

Concern 5. Won't feral alfalfa be a source of contamination?

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January 2009

Feral (wild growing) alfalfa can act as a bridge for moving genes from one seed field to another, and thus should be controlled to prevent gene flow in any area where seed production occurs, whether biotech or not. Feral alfalfa is primarily an issue in portions of Western states because little occurs elsewhere. Feral alfalfa will have low seed production for the reasons described in #3 plus damage from lygus bug and infection from seed-borne fungi when seed develops under damp conditions. Seed from any feral plants will contribute to new plants only over a very short term, but removing feral alfalfa from ditches and roads is a good idea for organic and export growers to prevent gene flow. If feral alfalfa is deemed a problem in a specific area, then it must be controlled as off types of alfalfa and other problem weeds are currently controlled using cultural and other herbicide methods.

Concern 6. Won't hard seed be a source of contamination?

Hard seed of alfalfa generally does not persist for more than one year in moist soils (Albrecht et al. 2008 Forage and Grazinglands), much less after years of hay production. To guard against hard seed carryover, seed growers take steps to eliminate residual alfalfa volunteers prior to planting. State Seed Certification Standards already require that the alfalfa seed field's history include a 2-year exclusion period before planting alfalfa for seed.

Concern 7. Much of hay in my area is cut late with mature seed – we have good farmers but weather, equipment problems force late cuttings.

Although late cuttings occasionally happen viable seed development is unlikely. However, plants must remain in field for 4 to 6 weeks after pollination of flowers for viable seed to form and longer for seed to shatter. Delaying harvest 1 to 2 weeks due to weather, equipment problems and other issues will cause little to no seed production in hay fields (see item #3). Furthermore, hay harvest should remove this small amount of seed so that it doesn't become a problem.

Concern 8. Organic producers may have difficulty growing organic hay.

No – there is no reason that organic growers can't continue to successfully grow organic hay. In fact the presence of Roundup Ready alfalfa hay in the marketplace may increase the value of organic hay, for buyers who are sensitive to biotech traits. Current demand for organic hay has been high, in spite of the introduction of Roundup Ready alfalfa. There are a number of growers who currently grow both Roundup Ready alfalfa and organic hay on the same farm without difficulty. Organic growers should 1) select conventional seed that is tested for the trait if their customers have set a standard of no adventitious presence, 2) take simple steps to protect their crop from gene flow and 3) identify hay lots after harvest. Feedstuffs can be tested to ensure low biotech levels desired for these markets. Organic growers currently are certified to show that their crops are not grown with pesticides or non-organic fertilizers, and similar steps can be taken to show that they do not use genetically engineered crops.

Concern 9. Couldn't we lose our entire export market?

No. While export growers and buyers are sensitive to the presence of biotech traits in crops, they have developed market-assurance methods to demonstrate that they are marketing non-biotech alfalfa hay, including testing to assure buyers of the non-biotech status of hay. Japan, Taiwan, and Korea (main U.S. hay market) already use biotech corn and soybeans and have accepted some RR alfalfa hay. The European Union has approved use of certain biotech varieties of corn and soybeans in food and feedstuffs. While significant in some growing regions in the US, exported hay represents less than 1 % of total alfalfa hay production.

Concern 10. Isn't the research biased by the seed companies that stand to gain most?

RR technology at has been evaluated at many universities. This research is independent of the concerned commercial parties. The goal is to independently test a technology for its viability and environmental safety for farmers and for the general public. These studies must be well-designed, accurate and can only be published only after review by anonymous individuals from other institutions selected for impartiality.

Concern 11. Won't the Roundup Ready gene in alfalfa have a negative effect on insects, diseases, other biota, or the environment?

There is currently no evidence that this gene would have a negative effect on insects or animals, or the environment. The Roundup Ready gene has been thoroughly tested as other crops were released (corn, soybeans, cotton) and no impact on any other biota has been found. No toxicology issues have been identified with roundup ready alfalfa fed to animals. In the past ten years, billions of tons of corn, soybeans, cotton and alfalfa have been

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January 2009

produced with this gene, and there has been no documented harm to animals, humans or wildlife. In fact the use of Roundup would replace some more toxic pesticides that have been used and found in ground water (e.g. Velpar).

Concern 12. Farmers can't/won't follow stewardship protocols.

All technology requires stewardship by farmers (e.g. fertilizer use, pesticide use, irrigation). Farmers must be educated about stewardship needed and required to use appropriate stewardship for any technology. The possibility of gene flow is no different in scope than controlling pesticide drift, fertilizer contamination from conventional farms, or for that matter, the influence of weeds from organic fields that may contaminate neighbor's fields. Good farmers know how to do this.

Concern 13. Won't there be weed resistance to Roundup from use of RR alfalfa?

Weed resistance and weed shifts are issues with all herbicides. New management programs have always resulted in shifts in weed pressure. For example, no-till crop production has resulted in different weed problems than when crops were grown with conventional tillage. Resistance to glyphosate has occurred in row crop situations. Inclusion of alfalfa might actually slow increase of resistant populations of weeds because an additional mechanical control (frequent hay harvest) is being added to the weed management program. Techniques are readily available to avoid weed shifts or weed resistance using the Roundup Ready system as detailed in a recent article (Orloff et al., 2008).

Concern 14. Risk far outweighs reward/Do we really need this? Are we willing to take this kind of gamble?

There is also a risk with NOT moving ahead with a technology that has clear potential benefits to farmers and the environment. Currently, many animals are killed or hurt each year by weedy alfalfa fields – something that Roundup Ready technology could help address. Also, some of the conventional herbicides have been found in well water – something not true with glyphosate. Additionally, Roundup Ready alfalfa would allow farmers to control tough weeds for which no other good method of control exists (e.g. winter annuals such as chickweed, wild garlic, wild onion, perennials such as dandelion. difficult weeds such as nutsedge and dodder, and poisonous weeds such as groundsel).

Further, if this breeding methodology is permanently banned, it would mean fewer genetic advancements for alfalfa in the future. Some traits currently under development, such as a low lignin gene that could mean higher forage yield and fewer cuttings for farmers, a leaf retention gene to retain leaves through harvesting process, genes which confer pest resistance, or genes to increase bypass protein, would never be available to farmers. It is not reasonable or fair to farmers to restrict a technology from use in alfalfa that is available in other crops.

A series of articles on biotech alfalfa and coexistence of GE and conventional alfalfa seed and hay production is available at http://www.alfalfa.org/CSCoexistenceDocs.html and http://alfalfa.ucdavis.edu/+producing/biotech.aspx.

In summary, it is essential that alfalfa growers and the industry understand how to use this important new genetic tool, while at the same time, protecting those farmers who don't wish to adapt it. Research has proceeded with great deliberation in the development of Roundup Ready alfalfa and shown it to be a good tool that will benefit many farmers. Like every other tool, it must be used with care and appropriate stewardship. It is important for the industry to manage for coexistence of biotech-adapting and non biotech-adapting farmers, since other important biotech traits are being developed which might be much greater benefit to farmers and society.

Dr. Dan Putnam, University of California
Dr. Dan Undersander, University of Wisconsin

Appendix J

Roundup Ready Alfalfa Harvesting Study, Study #3482 (Originally Submitted as Appendix 6 to Monsanto/FGI Comments to Draft EIS)

ROUNDUP READY ALFALFA HARVESTING STUDY

Study #3482

MONSANTO
imagine™

Prepared By:

Market Probe

St. Louis, Missouri

January 2010

METHODOLOGY

- To achieve the objectives set for this study, a total of 200 telephone interviews were completed with growers who had Roundup Ready alfalfa acres in production in 2009 and/or 2010. The interviews were distributed regionally:

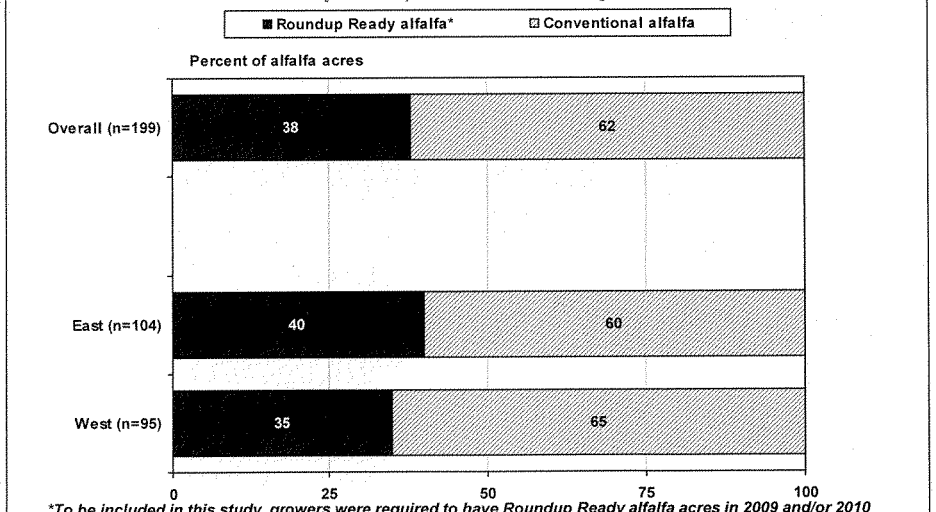
  West: WA/OR/ID/CA/NV/UT/AZ . . . . . N=95
  East: All other states, east of the Rockies . . . . . N=105

- Participants were screened on the following criteria:
  - Actively involved in farming
  - Primarily responsible for decisions concerning the management practices followed on alfalfa crop
  - Had 30+ acres of Roundup Ready alfalfa in production in 2009 or 2010
  - Not, nor anyone in household, working for a farm chemical manufacturer, distributor, or dealer
  - Not, nor anyone in household, working for a seed company, or as a farmer dealer
  - Not, nor anyone in household, raising alfalfa seed for a seed company

- A monetary honorarium was paid ($40-West and $20-East) to all participants. Interviews were conducted between January 18th and 25th, 2010.

2010 Roundup Ready Alfalfa Penetration

[Base=Respondents able to estimate]

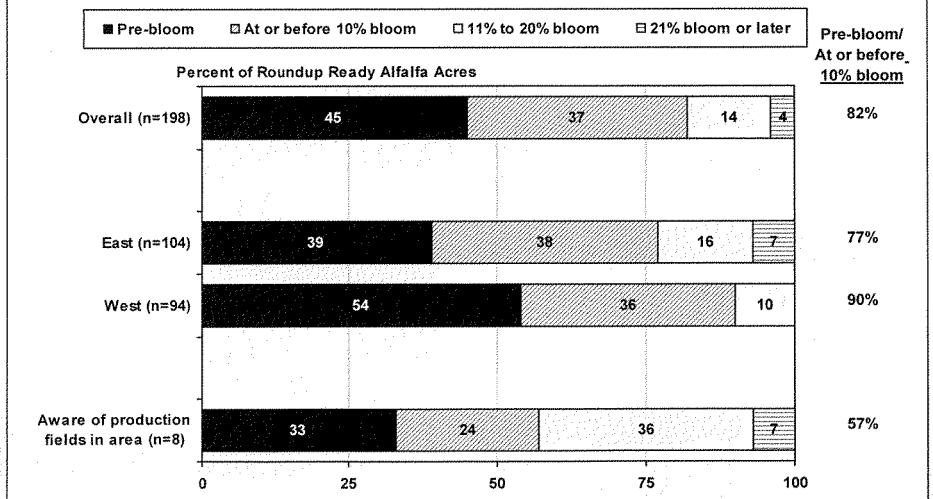


To be included in this study, growers were required to have Roundup Ready alfalfa acres in 2009 and/or 2010

Q.D How many acres of alfalfa, including both established and newly seeded, will you have this year in 2010?
Q.E And, how many, if any, of these [Q.D] acres are Roundup Ready alfalfa, and how many are conventional alfalfa?

Percent Of Roundup Ready Alfalfa Harvested At Specific Stage In 2009

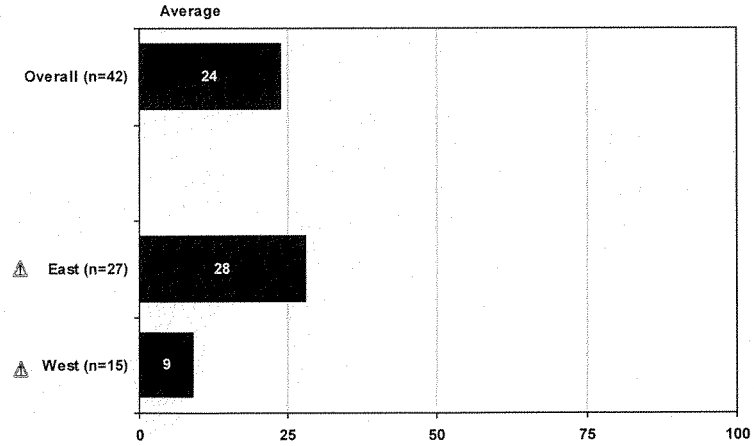
[Base=Respondents harvesting Roundup Ready alfalfa and able to estimate]



Q.3 In 2009, what percent of your total Roundup Ready alfalfa did you harvest:

Of the 18% of Occasions When Harvest Occurred After 10% Bloom, What Percent Were Due To Bad Weather?

[Base=Respondents harvesting at least some Roundup Ready alfalfa after 10% bloom, and able to estimate]



Q.4b What percent of the time was your decision to harvest Roundup Ready alfalfa after 10% bloom due to bad weather?

Appendix K

Fitzpatrick, S. and G. Lowry. 2010. Alfalfa Seed Industry Innovations Enabling Coexistence. Proceedings of the 42nd North American Alfalfa Improvement Conference, Boise, Idaho, July 28-30, 2010

Alfalfa Seed Industry Innovations Enabling Coexistence

S. Fitzpatrick* and G. Lowry**

The alfalfa seed industry has recently implemented two complementary programs that together enable mutual coexistence between conventional and Roundup Ready alfalfa (RRA) seed producers. The 2010 Alfalfa Seed Stewardship Program (ASSP-2010) is an identity preserved process-based certificate offered by state seed certification agencies. It was developed by the Association of Official Seed Certifying Agencies (AOSCA) designed to serve GE-trait sensitive conventional seed producers (e.g., export). In 2008, the Best Management Practices for RRA Seed Production (BMPs) was adopted by the National Alfalfa & Forage Alliance. These BMPs are required coexistence protocols that apply only to RRA seed-producing companies (i.e., no new requirements are imposed upon external conventional seed producers). These market-driven, science-based programs were developed with the involvement of alfalfa industry stakeholders over a 5-year period (2005 to 2010) using all available market and gene flow data. An array of stakeholders were involved that represented diverse segments of the alfalfa seed and hay industries: scientists, seed certifiers, breeders, exporters, marketers, producers, growers and organic. These new programs are independent from and more stringent than AOSCA or OECD Seed Certification Programs. Forage Genetics and Pioneer Hi-Bred International (the only companies producing RRA seed), have collectively reported to inspectors that in 2009 greater than 97% of their conventional seed lots were produced without detection of the RRA trait (>500 lots tested with <0.00% RRA). If detected, AP was less than 0.5% (overall lot average <0.1%).

Seed Program	**No Program (e.g., common seed)**	**USDA National Organic Program Certification**	**Certified Seed**	**Roundup Ready Alfalfa (RRA) Seed**	**AOSCA AASP-2010 Identity Preserved, Certified Seed**
Market	U.S. domestic conventional (baseline)	Organic forage planting	U.S domestic conventional & RRA seed	U.S. domestic RRA seed	U.S. conventional seed for export
Purity Standard or Objective	n/a	No official purity standards; process-based requirements	≤1% off types	≤ 0.5% GE in *neighboring* conventional seed production	Non-detect GE
Spatial isolation from other seed field	n/a	Customized farm plan; not uniform mitigation standard	165 ft	900 ft to 3 mi at RRA seed field planting (pollinator specific)	≥5 miles
Program conforms to:	n/a	USDA-AMS National Organic Program	Federal Seed Act	Industry consensus and RRA seed co. contracts	AOSCA I. P. Program
Program monitored by:	n/a	Local Organic Certifying Agency	State Seed Certifying Agency	State Seed Certifying Agency	State Seed Certifying Agency
Program obligations fulfilled by:	n/a	Organic, conventional grower	Seed company and seed grower	RRA seed company and seed grower	GE-sensitive seed company and conventional seed grower
Growers using the program:	Conventional only	Conventional only	Both, conventional and RRA	All RRA, only	Conventional only

* Forage Genetics International, West Salem, WI **Idaho Crop Improvement Association, Meridian, Idaho

DRAFT

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By APHIS BRS Document Control Officer at 3:19 pm, Aug 09, 2010

MONSANTO

KWS

July 29, 2010

Michael C. Gregoire
Deputy Administrator
Biotechnology Regulatory Services
Animal and Plant Health Inspection Service
U.S. Department of Agriculture
4700 River Road, Unit 98
Riverdale, MD 20737

Re: Petition 03-323-01p for Non-Regulated Status, Roundup Ready® Sugarbeet -1; Event H7 Supplemental Request for "Partial Deregulation" or Similar Administrative Action

Dear Mr. Gregoire:

Monsanto Company ("Monsanto") and KWS SAAT AG ("KWS") jointly filed the petition for nonregulated status for Roundup Ready sugarbeet[1] Event H7-1 ("RRSB") which USDA's Animal and Plant Health Inspection Service ("APHIS") previously granted in March 2005. In light of recent developments in litigation, and with the support of thousands of sugarbeet growers nationwide and all sugarbeet cooperatives, processors and seed-producers, Monsanto and KWS jointly submit this supplemental request for "partial deregulation" or similar administrative action, as set forth below.

Background

On March 17, 2005, APHIS granted nonregulated status for RRSB following nearly 100 field trials, a 60-day comment period and issuance of an environmental assessment ("EA") concluding that the event presented "no significant impact on the human environment." In the years thereafter, a majority of our nation's sugarbeet growers adopted RRSB; wide-scale RRSB seed production began by 2006, and the multi-year process to develop appropriate RRSB varieties for growers in 10 states resulted in RRSB cultivation on roughly 95% of all U.S. sugarbeet acreage. The Government of Canada likewise approved RRSB for cultivation and human and animal consumption, and the European Union, Japan, Mexico, South Korea, Australia, New Zealand, China, Colombia, Russia, Singapore, and the Philippines each approved importation of sugar and other products derived from RRSB. Today, RRSB is processed into roughly half of our nation's domestic sugar supply.

[1] ® Roundup and Roundup Ready are registered trademarks of Monsanto Technology LLC.

On September 21, 2009, however, a Federal district court in San Francisco ruled that APHIS's 2005 EA for RRSB did not adequately evaluate potential cross-pollination from RRSB seed crops to other crops. The court held that APHIS "did not consider the effects of gene transmission on conventional farmers and consumers of sugar beet seed or of gene transmission to the related crops of red table beets and Swiss chard" and noted that such "seed production takes place primarily in the Willamette Valley of Oregon." *Center for Food Safety v. Vilsack ("CFS")*, No. 08-484, 2009 WL 3047227, *5, 13-14 (N.D. Cal. Sept. 21, 2009). That litigation is currently in the remedies phase, where the plaintiffs in the suit have sought a judicial order halting further planting of RRSB. Representatives of the thousands of sugarbeet growers nationwide along with sugarbeet cooperatives and processors, the seed companies who produce RRSB seed and Monsanto have intervened in this suit to urge the court not to halt ongoing or future RRSB cultivation. Specifically, the district court has been presented with evidence that an order immediately halting RRSB planting would have profound consequences for the nation's growers and many other parties, including that:

- Farming communities could suffer losses exceeding $2 billion;
- Approximately eight sugarbeet processing facilities would close (likely forever);
- More than 5,500 jobs would be lost; and
- The resulting domestic sugar shortages would, under USDA estimates, cost consumers $2.972 billion in 2011 alone.

Recently, the Supreme Court has addressed deregulation of a similar crop, Roundup Ready alfalfa, and provided significant guidance applicable here. *See Monsanto Co. v. Geertson Seed Farms*, No. 09-475, -- S. Ct. --, 2010 WL 2471057 (2010). The Supreme Court concluded that, even where a court has held that APHIS has violated NEPA with respect to a complete deregulation determination,"[a]t that point, it was for the agency [APHIS] to decide whether and to what extent it would pursue a *partial* deregulation." *Id.* at *13. "If ... a limited and temporary deregulation satisfied applicable statutory and regulatory requirements, it could proceed with such a deregulation even if it had not yet finished the onerous EIS required for complete deregulation." *Id.* The Supreme Court went on to identify a combination of geographic restrictions, isolation distances, and enforcement measures that could serve to eliminate any risk of "injury at all, much less irreparable injury." *Id.* at *15.

In light of this recent Supreme Court ruling, the Government has represented to the district court in San Francisco that, in the event the court vacates the existing RRSB deregulation, APHIS has authority to deregulate "in part" to "allow planting to occur under the conditions proposed by APHIS while the EIS is being prepared." As APHIS explained, it could take such action if "[i]ntervenors submitted a new petition or a supplement or amendment to a previous petition for a determination of nonregulated status of RRSB." Federal Defs.' Supp. Br. on Perm. Inj. Relief at 1, 13-14. The Government further explained that the Supreme Court's decision in "*Monsanto* clearly indicates that this type of interim administrative action would be permissible." *Id.* at 14; *see also Monsanto*, 2010 WL 2471057, at *15 (citing "representation from the Solicitor General" that APHIS has authority to do so). Separately, based on its expert analyses and review, APHIS has proposed to the district court a series of carefully tailored interim measures designed to address any potential risk of harm to other parties from continued cultivation of RRSB during the time period necessary for APHIS to reevaluate the RRSB petition for nonregulated status. Although there has been no record of any harm to any grower of any other crops in the multiple years of wide-scale RRSB production without these restrictions in place, the intervenors in this litigation have agreed that these additional interim requirements will reduce further an already negligible potential for any impact to other parties from RRSB.

Request for Interim Measures

With the support of each of the sugarbeet growers, cooperatives, processors and seed companies who have intervened in the pending RRSB litigation, Monsanto and KWS now jointly request that, in the event the court in the RRSB litigation vacates the existing deregulation determination, APHIS grant nonregulated status *in part* or take similar administrative action to authorize continued cultivation of the RRSB crop subject to the carefully tailored interim measures proposed by APHIS. Petitioners believe this request is appropriate in this context because:

(1) As APHIS explained its recent Supplemental Brief, the U.S. Supreme Court has clarified that APHIS has authority to implement interim measures through partial deregulation or similar means for this purpose;

(2) Sugarbeet growers nationwide, along with sugarbeet cooperatives, processors, seed companies and other interests, face significant harm from any halt in RRSB planting, cultivation, harvesting or processing; and

(3) Petitioners are requesting that APHIS implement measures that APHIS has already itself reviewed, analyzed and supported in the litigation context.

Attached to this letter is an Environmental Report, providing additional analysis of the proposed interim measures. The analysis in APHIS's original EA addressing Monsanto and KWS's petition, along with the 5000-page administrative record relating thereto and this Environmental Report all support petitioners' request for partial deregulation or similar administrative action.

Thank you very much for your attention to this matter.

Sincerely,

H. Keith Reding, Ph.D.
Regulatory Affairs Manager, Monsanto

Philip von dem Bussche
Chairman of the Executive Board of KWS SAAT AG

Dr. Peter Hofmann
Head of Sugar Beet Division

ENVIRONMENTAL REPORT
Interim Measures for Cultivation of Roundup Ready® Sugar Beet Event H7-1

July 30, 2010

ACRONYMS AND ABBREVIATIONS

ACCase	acetyl-CoA carboxylase (enzyme)
a.e.	acid equivalent
ALS	acetolactate synthase (enzyme)
AMS	Agricultural Marketing Service (USDA)
AP	Adventitious presence
APHIS	Animal and Plant Health Inspection Service (USDA)
APM	American Public Media
ARS	Agricultural Research Service (ARS)
ASTA	American Seed Trade Association
BNF	Biotechnology Notification Files
BRS	Biotechnology Regulatory Service (USDA APHIS)
CEQ	Council on Environmental Quality
CFIA	Canadian Food Inspection Agency
CFR	Code of Federal Regulations
CFS	Center for Food Safety
CMS	cytoplasmic male sterility
cPAD	chronic Population Adjusted Dose
CTIC	Conservation Technology Information Center
DEIS	Draft Environmental Impact Statement
DNA	Deoxyribonucleic Acid
EA	Environmental Assessment
EC	European Commission (EU)
EEC	Estimated Environmental Concentration
EFSA	European Food Safety Authority
EIQ	Environmental Impact Quotient
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency (US)
EPSPS	5-enolpyruvylshikimate-3-phosphate synthase (enzyme)
ER	Environmental Report
ERS	Economic Research Service (USDA)
EU	European Union
FDA	Food and Drug Administration (US)
FFDCA	Federal Food, Drug, and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act

FONSI	Finding of No Significant Impact
FQPA	Food Quality Protection Act
FSA	Farm Service Agency
FSANZ	Food Standards Australia New Zealand
ft	feet
GE	Genetic engineering or genetically engineered
GM	Genetically modified
GMO	Genetically modified organism
GPS	Global Positioning System
GR	Glyphosate resistant
GT	Glyphosate-tolerant
HQ	Hazard quotient
HTS	Harmonized Tariff Schedule
IM/NRC	Institute of Medicine and National Research Council
IPM	Integrated pest management
IPA	Isopropylamine
ISF	International Seed Federation
NASS	National Agricultural Statistical Service (USDA)
NEPA	National Environmental Policy Act
NOAEL	No-Observed-Adverse-Effect-Level
NOP	National Organic Program
NRC	National Research Council
OECD	Organization for Economic Cooperation and Development
OP	Open-pollinated
OSTP	Office of Science and Technology Policy
PCR	Polymerase chain reaction
PHI	Post Harvest Intervals
PNT	Plant with a Novel Trait
POEA	Polyethoxylated Tallow Amine
PPA	Plant Protection Act
PPE	Personal Protective Equipment
PPI	Pre-plant incorporated (herbicide)
rDNA	Recombinant DNA
RED	Reregistration Eligibility Decision

RfD	Reference Dose
RR	Roundup Ready®
R&D	Research and Development
SBRED	Sugar beet Research and Education Board of Minnesota and North Dakota
SOP	Standard Operating Procedures
TUG	Technology Use Guide
T-DNA	Transferred DNA
UC	University of California
U.S.	United States
USC	United States Code
USDA	US Department of Agriculture
USDC	U.S. District Court
USFWS	U.S. Fish and Wildlife Service
WCBS	West Coast Beet Seed Company
WHO	World Health Organization
WSSA	Weed Science Society of America
WVSSA	Willamette Valley Specialty Seed Association

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This Environmental Report (ER) examines the environmental impacts of continued cultivation of Roundup Ready® sugar beet event H7-1 (event H7-1) for a temporary period subject to a range of interim measures, including geographic restrictions, stewardship requirements and other limitations -- identified and analyzed by the US Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) in *Center for Food Safety v. Vilsack*, No. 08-484, N.D. Cal. This ER is provided in connection with the petitioners' supplemental request for non-regulated status *in part* (commonly known as "partial deregulation") for event H7-1. This document is intended to provide information that may be utilized by APHIS in complying with the National Environmental Policy Act (NEPA)[1] and its applicable regulations[2] either in connection with partial deregulation of event H7-1 or for any other regulatory or administrative action by APHIS adopting the interim measures addressed herein. The interim measures are intended to apply until APHIS completes its NEPA review of the petition for nonregulated status for event H7-1 and reaches a final determination regarding the petition.

The sugar produced from sugar beets, which were planted on approximately 1.2 million acres in the US in 2010, accounts for over half the US sugar production. Cash receipts for sugar beets were $1.3 billion in the 2007-2008 crop year. Event H7-1, which has been genetically engineered to be tolerant to the herbicide glyphosate, has been grown on a large scale in the US for multiple years and accounted for approximately 95 percent of the sugar beet planted in the US in the 2009/2010 crop year (USDA NASS, 2010b; USDA ERS, 2009a and 2009b).

1.1 PURPOSE OF THIS ER

1.1.1 Background

In 2003, under the requirements of the Plant Protection Act (PPA),[3] Monsanto Company and KWS SAAT AG (Monsanto/KWS) submitted a petition (Petition No. 03-323-01P) to APHIS for a determination of non-regulated status for event H7-1 and all progeny derived by conventional breeding from this event (Schneider, 2003). APHIS, through its Biotechnology Regulatory Service (BRS), is one of three federal agencies responsible for regulating biotechnology in the US under the Coordinated Framework described in Section 1.4. APHIS regulates genetically engineered (GE) organisms that may be plant pests, the Environmental Protection Agency

[1] NEPA of 1969, as amended; Title 42 of the US Code (42 USC) §§4321-4347
[2] Council on Environmental Quality (CEQ) regulations implement NEPA and are found in Title 40 of the Code of Federal Regulations (40 CFR), Parts 1500 through 1508. The U.S. Department of Agriculture has implemented NEPA regulations, which are found at 7 CFR Part 1b, as has APHIS, and those are found at 7 CFR part 372.
[3] 7 USC §§7701-7786

(EPA) regulates plant incorporated protectants and herbicides used with herbicide-tolerant crops, and the US Department of Health and Human Services' Food and Drug Administration (FDA) regulates food and animal feed. The FDA completed its consultation process for event H7-1 in 2004 and EPA agreed that its previous approval for glyphosate residue in sugar beet roots, tops and dried pulp was also applicable to event H7-1 ((Tarantino, 2004; Bonette, 2004; Schneider, 2003, p. 14). NEPA requires federal agencies to evaluate the potential impact of proposed major federal actions and consider such impacts during the decision-making process. After agency review for safety, including an evaluation of relevant scientific data and all public comments relating to potential plant pest risks and related environmental impacts, APHIS issued an EA pursuant to NEPA in 2005 (USDA APHIS, 2005). Based on that EA, APHIS reached a finding of no significant impact (FONSI) on the environment from the unconfined cultivation and agricultural use of event H7-1 and its progeny (USDA APHIS, 2005, p. 1). Accordingly, in March 2005, APHIS granted non-regulated status to event H7-1 (USDA APHIS, 2005, p. 26).

After event H7-1 was deregulated, the multi-year process of bringing it to commercial production began. Large scale commercial seed production began in 2006 to produce the seed crop used for planting root crops in 2008. Small scale root production occurred in 2006 and 2007. In January 2008, the Organic Seed Alliance, Sierra Club, High Mowing Organic Seeds, and the Center for Food Safety (CFS) filed a lawsuit against the USDA over its decision to deregulate event H7-1, claiming the USDA failed to take a "hard look" at the environmental effects of its decision to deregulate. The plaintiffs in the suit did not seek a preliminary injunction to halt planting. In September 2009, the court granted the plaintiffs' motion for summary judgment in the merits phase of the lawsuit, concluding that APHIS was required to prepare an environmental impact statement (EIS) before approving its deregulation of GE sugar beets. In December 2009, the court issued a schedule for the remedies phase of the lawsuit. At that point, representatives of thousands of family farms that were growing event H7-1 sugar beet root crops along with the four seed companies who produced seed and other interested parties were permitted to participate in the suit.

In May 2010, while the remedies phase of the lawsuit was proceeding, Cindy Smith, the APHIS Administrator, filed a declaration in the suit anticipating completion of the EIS in May 2012 (Smith, 2010b, pp. 7-8) and suggested that the court enter an order imposing certain interim measures that would allow continued cultivation of event H7-1. These interim measures would include geographic restrictions and a range of stewardship requirements, and would apply for a

temporary period pending completion of the EIS and the corresponding record of decision (ROD), and implementation of that decision. (Smith, 2010b, pp. 19-22). Alternatively, Administrator Smith proposed that the Court remand the case to APHIS with the intention that APHIS would take action to implement these interim measures administratively. On May 25, 2010, APHIS issued a notice of intent to prepare an EIS and a proposed scope of study (APHIS 2010).

On June 21, 2010, the U.S. Supreme Court ruled in litigation related to Roundup Ready® alfalfa, clarifying that a court in a NEPA case may not preemptively bar APHIS from issuing a "partial deregulation" or taking other administrative action to implement interim measures for cultivation of a genetically engineered crop while the agency completes an EIS evaluating complete deregulation. Monsanto Co. v. Geertson Seed Farms, No. 09-475, 561 U.S. (2010).

1.1.2 Purpose of and need for action.

The purpose of this ER, which has been prepared to support an anticipated EA, is to examine the environmental impacts of implementing interim measures, either through a partial deregulation of event H7-1 lines of glyphosate tolerant sugar beets or certain other administrative means. The interim measures have been identified to address concerns regarding potential impacts related to the planting and cultivation of event H7-1 while the EIS evaluating complete deregulation is being prepared. If APHIS concludes that an EA supports a FONSI for such interim measures, APHIS could decide to implement such measures through "partial deregulation" pending APHIS's determination on complete deregulation.

1.1.3 APHIS proposed interim measures/time frames for implementation

APHIS' proposed interim measures for Roundup Ready® sugar beets (RRSB), to be implemented either through a partial deregulation or other administrative means, are detailed below. These measures are the same as those proposed by Administrator Smith to the court (Smith, 2010b, pp. 19-22), along with time frames for implementation of those measures.

Interim measures Proposed by APHIS to the Court

Administrator Smith proposed the following interim measures in the lawsuit discussed above:

1) *Roundup Ready® Sugar Beet-Free Zone*

The planting of RRSB is prohibited in the entire State of California and in the State of Washington in the following counties west of the Cascades: Clallam, Jefferson, Grays Harbor, Island, Pacific, Mason, Thurston, Lewis, Cowlitz, Clark, Whatcom, Skagit, Snohomish, King,

Pierce, Skamania, San Juan, Kitsap, and Wahkiakum Counties. [These counties are shown in this ER in Figure 1-1].

2) *A Coexistence Zone for Beta Seed Crop Production in the Willamette Valley in Oregon*

   a. All parties to this action who grow *Beta* seed crops in the Willamette Valley must adhere to a four mile isolation distance between RRSB seed crops and other *Beta* seed crops.

   b. All parties to this action who grow *Beta* seed crops in the Willamette Valley must follow the Willamette Valley Specialty Seed Association (WVSSA) pinning procedures.

3) *Disclosure of Information Regarding Male Fertile RRSB Seed Crops.*

All growers of RRSB male fertile seed crops must provide locations with GPS coordinates to APHIS/BRS of any RRSB male fertile seed crops in the United States that exist at the time the Court's Order is issued or that are planted at any time during the interim period in which the EIS is being prepared. Information regarding existing plantings must be provided to APHIS within 30 days after issuance of the Order; information regarding future plantings during the interim period must be provided to APHIS within one week after the completion of planting of any RRSB male fertile seed crops. Within 60 days after issuance of the Order, APHIS/BRS shall set up a toll-free number that growers of non-GE *Beta* seed crops may use to request from APHIS/BRS the approximate distances from the nearest RRSB male fertile seed crop to their non-GE *Beta* seed crop.

Upon calling this number, the caller shall certify to APHIS/BRS that the caller is a grower of non-GE *Beta* seed crops or intends to grow non-GE *Beta* seed crops at an existing location in the United States. APHIS/BRS shall only provide to the caller the approximate distance from the nearest RRSB male fertile seed crop location to the caller's non-GE *Beta* seed crop.

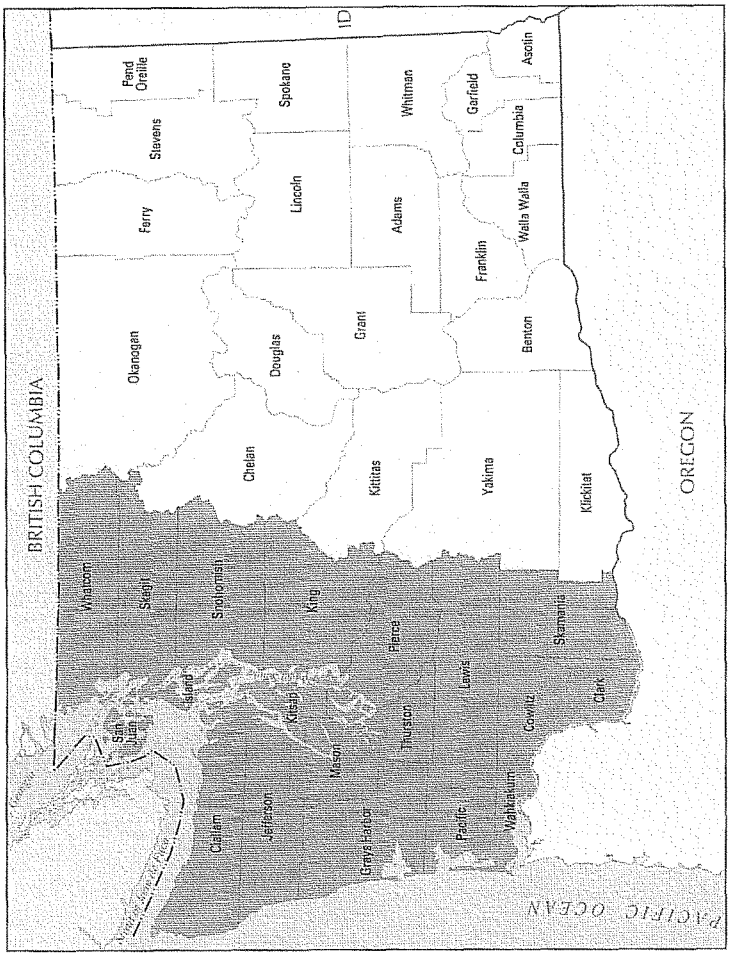


Figure 1-1. Roundup Ready® Sugar Beet-Free Zone
Sources: Smith, 2010b; National Atlas of the United States

4) *Measures to Prevent Mixing of Conventional Sugar Beet Seed and RRSB.*

RRSB seed producers shall follow protocols to ensure that mechanical mixing of material containing the RRSB trait and non-GE *Beta* seeds does not occur. Those protocols shall include:

a. A visual identification system for RRSB material (basic seed, stock seed, transplants (stecklings), and commercial seed) that accompanies seed material throughout the production system to delivery to ultimate purchaser;

b. A companion seed-lot based tracking and tracing system that is fully auditable;

c. Requirements for physical separation of RRSB material at all points in the seed production process from non-GE *Beta* material;

d. Requirements for monitoring, treating, and cleaning of all planting, cultivation and harvesting equipment to prevent RRSB seed, pollen or stecklings from being physically transferred out of production areas by inadvertent means;

e. Requirements for disposal of all unused RRSB stecklings by returning unused stecklings to the nursery field of origin and subsequent destruction through standard agricultural practices (physical destruction with tillage and chemical destruction in the subsequent crop););

f. Requirements for contained seed transport from field to cleaning facility, vehicle cleaning after transport of RRSB seed before use for other purposes, and devitalization of RRSB material derived from cleaning vehicles or processing facilities;

g. Prohibition on grower production of a RRSB seed and chard/red beet seed production on the same location/premises in the same year;

h. Prohibition on RRSB seed grower use or sharing of planting/cultivation equipment that might be used in a non-GE *Beta* seed production in the same growing year;

i. Prohibition on RRSB seed grower use of the same combine to harvest RRSB and non-GE *Beta* seed in the same year;

j. Provisions to force same-year sprouting of any RRSB seed left behind in production field for removal and destruction; plus 3-year monitoring of fields thereafter, along with removal and destruction of any beet plants;

k. Employee training in all aspects of a. through j. above;

l. No RRSB seed shall be cleaned or processed in any processing facility that also cleans and processes red beet or Swiss chard seed;

m. Recordkeeping to document compliance of a-l.

5) *Control of Any Bolters in the RRSB Root Crop Fields.*

All RRSB root crop growers must have contractual measures in place that require RRSB root crop growers to survey, identify, and eliminate any bolters in their root crop fields before they produce pollen or set seed.

6) *Control of Any Bolters in Harvested RRSB Root Crop in Outdoor Storage.*

All sugar beet processors or cooperatives that use RRSB must have measures in place to survey, identify, and eliminate any bolters in outdoor storage before they produce pollen or set seed.

7) *Third Party Audit for Compliance.*

APHIS will require third party audits to ensure that RRSB producers comply with requirements in paragraphs two and four above. APHIS expects that AMS [Agricultural Marketing Service], USDA, will be the third party auditor using its AMS-USDA Process Verified Program.

Time frame for Implementation

While certain interim measures could be implemented shortly after APHIS issues its interim order of partial deregulation or takes other administrative action regarding event H7-1 (e.g., Item 3), certain measures may require some additional time to fully implement. This ER makes the following assumptions as to when the various components of the interim measures would be implemented:

(1) *RRSB-free zone.* The sugar beet seed companies have represented that no RRSB sugar beet crops have been or would be planted in California or the subject counties in Washington State. Thus, these restrictions can be implemented immediately.

(2) *Willamette Valley coexistence zone*

While certain isolation distance and pinning requirements have already existed for years, the four-mile isolation distance and the pinning and audit requirements proposed in the interim measures will be implemented in full with the summer 2011 seed crop planting, which will occur in July and August of 2011 (Items 2 and 7). The current isolation distance provided by the Willamette Valley Specialty Seed Association pinning provisions is four miles between sugar beet seed crops on one hand and open-pollinated (OP) red beet or chard seed crops on the other. Most of these crops will have been pinned and planted by the end of August 2010.

3) *Disclosure of information regarding male fertile crops*

Time frames are included in the proposed interim measures, described above.

4) *Measures to prevent mixing of seed*

While these measures have already largely been implemented in the major seed production area, as discussed in Section 2.7.3 of this ER, we assume that full implementation will occur before the 2011 seed harvest.

5) *Control of bolters – root crop fields*

Contracts requiring control of bolters are in place currently for the 2011 spring planting.

6) *Control of bolters – root crop outdoor storage*

These measures will be in place before the 2011 harvest.

7) Third-party audits

Measures would be in place at the time of the partial deregulation or other administrative action imposing the interim measures.

1.2 RATIONALE FOR CREATION OF EVENT H7-1

Event H7-1 offers sugar beet growers a simpler, more flexible, and less expensive alternative for weed control relative to conventional weed control measures.

According to the World Agriculture Series volume *Sugar Beets*, "Weeds have been a major problem in sugar beet since the crop was first grown in the late 1700s" and "unlike insects, diseases and nematodes, weeds occur in all sugar beet fields every year, usually at populations that cause crop failure unless controlled" (May and Wilson, 2006, p. 359). Other researchers,

working before the introduction of event H7-1, have reported that "weed management is one of the main production costs with sugar beet" (Odero et al, 2008, p. 50).

As discussed in detail in Section 2.5, prior to widespread cultivation of event H7-1, sugar beet growers used a variety of means to control weeds, and herbicides are a key component. Herbicides are used by virtually all sugar beet growers; in 2000, approximately 98 percent of planted sugar beet acres received one or more herbicide applications (Ali, 2004, Table 4). In the 2000 growing season, 12 different active ingredients formulated as various herbicide products were commonly used in U.S. sugar beet production with a total of about 1.4 million pounds of herbicides applied (USDA APHIS, 2005, pp. 6-7). Typical conventional weed control consists of multiple applications of several different herbicides, often combined with hand or mechanical weeding (Odero et al, 2008).

Glyphosate is little-used for conventional sugar beets (those without glyphosate tolerance) because it damages the plants. With glyphosate-tolerant sugar beets, growers have an additional option for weed control.

1.3 COURT RULING AND ISSUES IDENTIFIED

During the lawsuit discussed above, the court identified certain specific issues as requiring additional analysis by APHIS (US District Court [USDC] 2008). These issues are described below and are addressed in the Affected Environment and Environmental Consequences sections of this ER. Additionally, this ER addresses issues that were not found to be problematic by the court in APHIS' initial EA. These issues are nevertheless addressed again here to ensure full disclosure and analysis of any potential impacts associated with partial deregulation of event H7-1 under the proposed interim measures.

1.3.1 Gene transmission from H7-1 sugar beets in production fields

Sugar beet is largely wind pollinated and has a biennial, two year life cycle when grown for seed; plants develop a large root the first year, then overwinter and flower, producing a seed stalk the second year. When grown to produce sugar, sugar beet roots are harvested during the first year while still in the vegetative (non-flowering) phase. Sugar beets grown for root crops rarely flower and thus rarely produce any pollen. However, certain conditions such as low temperatures after planting and longer day length can occasionally cause the sugar beet to "bolt" or produce a seed stalk (which can ultimately flower) during the first growing season (Bell 1946; Jaggard *et al.* 1983; Durrant and Jaggard 1988). Thus, further analysis to determine the

potential for gene transmission from event H7-1 being grown for root production to conventional sugar beets was conducted and is discussed in Section 3.3 of this ER.

1.3.2 Gene transmission to conventional sugar beets in seed production

Unlike sugar beet root production, seed production requires that the plants flower, become pollinated and develop seed. The court concluded that APHIS did not take a "hard look" at the potential for gene transmission in seed production in its initial EA in reference to the 2003 petition, and did not consider the fact that isolation distances set by the Oregon Seed Certification Standards are voluntary; whether the isolation distances were actually followed and are likely to be followed in the future; or if the isolation distances are sufficient to protect the non-GE crops that are inter-fertile with sugar beets. Therefore, further analysis to determine the potential for gene transmission from sugar beets being produced for seed production was conducted and is discussed in Section 3.9 of this ER.

1.3.3 Gene transmission to red table beets and Swiss chard

Cross-pollination between cultivated sugar beet and sexually compatible *Beta* species can occur when these plants grow close together and have overlapping flowering periods. The court found that because sugar beet pollen can travel large distances by wind, and because seed for sugar beets, Swiss chard, and table beets (which are all members of the same species and are all sexually compatible) are all grown in one valley in Oregon (albeit principally in different parts of the same valley), additional analysis is required to determine whether deregulation may significantly affect the environment as a result of any potential cross-pollination. Therefore, further analysis was conducted and is discussed in Sections 3.5 and 3.6 of this ER.

1.3.4 Socioeconomic impacts

The court found that APHIS failed to analyze in its initial EA the socio-economic impacts of deregulating event H7-1 on farmers and processors seeking to avoid GE sugar beets and derived products, stating,

> *Economic effects are relevant and must be addressed in the environmental review "when they are 'interrelated' with 'natural or physical environmental effects.'" Ashley Creek Phosphate Co. v. Norton, 420 F.3d 934, 944 (9th Cir. 2005) (emphasis in original) (quoting 40 C.F.R. 1508.14); see also Geertson Seed Farms v. Johanns, 2007 WL 518624, *7 (N.D. Cal. Feb. 13, 2007). In Geertson Seed Farms, the court found that "the economic effects on the organic and conventional farmers of the government's deregulation decision are interrelated with, and, indeed, a direct result of, the effect on*

*the physical environment; namely, the alteration of a plant specie[s]' DNA through the transmission of the genetically engineered gene to the organic and conventional [crop]." Id., 2007 WL 518624, *8 (emphasis added).*

The court held that APHIS was required to consider these effects in assessing whether the impact of its proposed action of deregulation was significant. Therefore, further analysis was conducted and is discussed in Section 3.17 of this ER.

1.3.5 Willingness of buyers to accept sugar derived from GE sugar beets

The court's ruling included a reference to a 2004 comment from Imperial Sugar, a company that at that time processed sugar beets (but no longer does) and currently produces and markets only cane sugar. Imperial Sugar raised a concern in response to the petition for deregulation that buyers of industrial and consumer sugars have expressed reluctance or opposition to receiving sugar derived from GE sugar beet. Imperial Sugar's opinion was that the industrial buyers' reluctance was caused by their belief that consumers would react negatively to products containing or derived from GE crops. Imperial Sugar was therefore concerned that industrial buyers would be unwilling to test the reaction of consumers by using sugar from event H7-1 in their branded products.

Currently, event H7-1 sugar beet is processed into a large percentage of our domestic sugar supply, and has been well accepted. Nevertheless, further analysis of this issue was conducted and is discussed in Section 3.11 of this ER.

1.3.6 Restrictions/labeling requirements by some countries on GE products

Imperial Sugar also commented that some countries will not allow GE products to be imported and that many nations require labeling of food products with GE content. However, less than two percent of the sugar produced in the US is exported (USDA FAS, 2010), and exports of products derived from event H7-1 sugar beets are expressly allowed in many foreign countries. Further information is available in Section 3.11 of this ER.

1.3.7 Potential for development of glyphosate-resistant weeds

As the adoption of glyphosate-tolerant crops has grown, the use of glyphosate has increased (National Research Council [NRC], 2010, Figures S-1, S-2, and S-3; Young, 2006). Concerns have been expressed that increased use of glyphosate may lead to development of glyphosate-resistant weeds. Further information is available in Sections 2.5 and 3.12 of this ER.

1.3.8 Cumulative effects of increased use of glyphosate

Further analysis of cumulative impacts from increased use of glyphosate was conducted and is discussed in Section 4 of this ER. However, since this ER is intended to address only the period of time until the EIS is completed, cumulative effects are considered for that time period.

1.4 FEDERAL REGULATORY AUTHORITY – COORDINATED FRAMEWORK

Interagency coordination in scientific and technical matters is the responsibility of the federal Office of Science and Technology Policy (OSTP), which was established by law in 1976. A large part of the OSTP's mission is "to ensure that the policies of the Executive Branch are informed by sound science" and to "ensure that the scientific and technical work of the Executive Branch is properly coordinated so as to provide the greatest benefit to society" (OSTP, undated).

In 1986, the OSTP published a "comprehensive federal regulatory policy for ensuring the safety of biotechnology research and products", the *Coordinated Framework for the Regulation of Biotechnology* (Coordinated Framework) (OSTP, 1986). The OSTP concluded that the goal of ensuring biotechnology safety could be achieved within existing laws (OSTP, 1986).

The Coordinated Framework specifies three federal agencies responsible for regulating biotechnology in the US: USDA's APHIS, the EPA, and the FDA. APHIS regulates GE organisms under the Plant Protection Act of 2000 (PPA). EPA regulates plant-incorporated protectants and herbicides used with herbicide-tolerant crops under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and Federal Food, Drug, and Cosmetic Act (FFDCA). FDA regulates food (including animal feed, but not including meat and poultry, which is regulated by USDA), including food and feed produced through biotechnology, under the authority of the FFDCA. Products are regulated according to their intended use and some products are regulated by more than one agency. Together, these agencies ensure that the products of modern biotechnology are safe to grow, safe to eat, and safe for the environment. USDA, EPA, and FDA enforce agency-specific regulations to products of biotechnology that are based on the specific nature of each GE organism.

In 2001, in a joint CEQ/OSTP assessment of federal environmental regulations pertaining to agricultural biotechnology, the CEQ and OSTP found that "no significant negative environmental impacts have been associated with the use of any previously approved biotechnology product" (CEQ/OSP, 2001, p. 1).

For glyphosate-tolerant sugar beet event H7-1, the plant is reviewed by USDA and FDA, whereas EPA is responsible for registering the use of the glyphosate herbicide and establishing a tolerance for allowable glyphosate residues. As indicated herein, although certain issues such as weed resistance and impacts of glyphosate on animals or plants are addressed by EPA (not APHIS), this ER nevertheless addresses those issues.

1.4.1 USDA Regulatory Authority

The Animal and Plant Health Inspection Service (APHIS) Biotechnology Regulatory Service (BRS) mission is to protect US agriculture and the environment using a dynamic and science-based regulatory framework that allows for the safe development and use of GE organisms. Under its authority from the PPA, APHIS regulates the introduction (importation, interstate movement, or release into the environment) of certain GE organisms and products.[4] A GE organism is presumed to be a regulated article if the donor organism, recipient organism, vector, or vector agent used in engineering the organism belongs to one of the taxa listed in the regulation[5] and is also presumed to be a plant pest. APHIS also has authority under these rules to regulate a GE organism if it has reason to believe that the GE organism may be a plant pest or APHIS does not have sufficient information to determine that the GE organism is unlikely to pose a plant pest risk.[6]

Under APHIS' regulations a person may petition APHIS to evaluate submitted data and determine that a particular regulated article is unlikely to pose a plant pest risk, and, therefore, should no longer be regulated.[7] The petitioner is required to provide information related to plant pest risk that the agency may use to determine whether the regulated article is unlikely to present a greater plant pest risk than the unmodified organism.[8] If the agency determines that the regulated article is unlikely to pose a plant pest risk, the GE organism will be granted nonregulated status. In such a case, APHIS authorizations (i.e. permits and notifications) would no longer be required for environmental release, importation, or interstate movement of the non-regulated article or its progeny.

It was under these regulations that Monsanto/KWS submitted the petition for a determination of non-regulated status for event H7-1 (Schneider, 2003). Event H7-1 sugar beets were considered regulated because they contain non-coding DNA segments derived from plant

[4] 7 C.F.R. §.340
[5] 7 C.F.R. §.340.2
[6] 7 C.F.R. §.340.1
[7] 7 C.F.R. §.340.6 entitled "Petition for determination of nonregulated status"
[8] *Id.* §340.6(c)(4)

pathogens and the vector agent used to deliver the transforming DNA is a plant pathogen (See Section 3.1 for a discussion of these concepts) (APHIS, 2005, p. 4).

1.4.2 EPA regulatory authority

EPA is responsible for regulation of pesticides (including herbicides such as glyphosate) under the FIFRA.[9] FIFRA requires that all pesticides be registered before distribution, sale, and use, unless exempted by EPA regulation. Before a product is registered as a pesticide under FIFRA, it must be shown that when used in accordance with the label, it will not result in unreasonable adverse effects on the environment. EPA granted the registration of glyphosate for use over the top of sugar beets on March 31, 1999.

Under the Federal Food, Drug, and Cosmetic Act (FFDCA), as amended,[10] pesticides added to (or contained in) raw agricultural commodities generally are considered to be unsafe unless a tolerance or exemption from tolerance has been established. EPA establishes residue tolerances for pesticides under the authority of the FFDCA. EPA is required, before establishing pesticide tolerance to reach a safety determination based on a finding of reasonable certainty of no harm under the FFDCA, as amended by the Food Quality Protection Act of 1996 (FQPA). The FDA enforces the tolerances set by the EPA. EPA established a tolerance for glyphosate residue found on beets, including sugar, roots, tops, and dried pulp on April 14, 1999 (64 Fed. Reg. 18360).

1.4.3 FDA regulatory authority

In 1992 FDA, which has primary regulatory authority over food and feed safety, published a policy statement in the Federal Register concerning regulation of products derived from new plant varieties, including those genetically engineered (FDA, 1992). Under this policy, FDA uses a consultation process to ensure that human food and animal feed safety issues or other regulatory issues (e.g. labeling) are resolved prior to commercial distribution of a bioengineered food. Monsanto/KWS submitted a food and feed safety and nutritional assessment summary for event H7-1 to FDA in April 2003. FDA completed its consultation process in August 2004 (Tarantino, 2004; Bonette, 2004).

[9] 7 USC §136 et seq.
[10] 21 U.S.C. § 301 et seq.

1.5 THE NATIONAL ORGANIC PROGRAM AND BIOTECHNOLOGY

Congress passed The Organic Foods Production Act of 1990 (OFPA) to avoid the confusion and misrepresentation then taking place in the "organic" marketplace.[11] The OFPA required the USDA to establish a National Organic Program (NOP) to develop uniform standards and a certification process for those producing and handling food products offered for sale as "organically produced."[12] The OFPA requires certification under the NOP, which was finalized in 2000, to be process-based.[13] "The certification process does not guarantee particular attributes of the end product; rather it specifies and audits the methods and procedures by which the product is produced" (Ronald and Fouche, 2006). The NOP defines certain "excluded methods" of breeding that cannot be used in organic production, describing them as "means that are not possible under natural conditions or processes."[14] Along with genetic engineering, three other modern breeding techniques are specified as "excluded methods" in the regulations.[15] Thus, a certified organic grower cannot intentionally plant seeds that were developed by these specific excluded methods. However, because "organic" is based on process and not product, the mere presence of plant materials produced through excluded methods in a crop will not jeopardize the integrity of products labeled as organic, as long as the grower follows the required organic production protocol. Also, other modern breeding methods - for example, induced radiation or chemical mutagenesis - are not specified as excluded methods by the NOP (discussed in Section 3.1.1).

All organic growers' production plans must be approved by an organic certifying agent before the farm can be certified as "organic."[16] Such plans must include, among other things, steps the organic grower is taking to avoid what the NOP refers to as "genetic drift" from any neighboring crops using excluded methods.[17] Certification must include on-site inspections of the farm to verify the procedures set forth in the organic production plan.[18]

Thus, the NOP recognizes the coexistence of organic growers with neighboring growers who may choose to grow products developed using certain methods of biotechnology. So long as an organic grower follows an approved organic method of production that seeks to avoid contact

[11] 7 USC § 6501 *et seq.*
[12] 7 C.F.R. Part 205, announced at 65 Fed. Reg. 80548 (Dec. 21, 2000).
[13] 7 U.S.C. 6503(a).
[14] 7 C.F.R. § 205.2
[15] *Id.*
[16] *See* 7 C.F.R. Part 205, Subpt. E.
[17] *See id.* at 205.201; 65 Fed. Reg. at 80556 (discussing "genetic drift").
[18] 7 C.F.R. § 205.403.

with these specific biotechnology-derived crops, if some residue of the biotechnology-derived plant material is later found in the organic crop (or food produced from it), neither the crop (or food) nor the organic farm is in danger of losing its organic status. No grower or seed producer has lost organic certification due to inadvertent transmission of genetic material from a genetically engineered crop.

In the context of the genetic drift discussion, in the preamble of the NOP regulations, USDA emphasized that it is the use of excluded methods as a production method that is prohibited, not the mere presence of a product of excluded method:

> It is particularly important to remember that organic standards are process based. Certifying agents attest to the ability of organic operations to follow a set of production standards and practices that meet the requirements of the Act and the regulations. This regulation prohibits the use of excluded methods in organic operations. The presence of a detectable residue of a product of excluded methods alone does not necessarily constitute a violation of this regulation. As long as an organic operation has not used excluded methods and takes reasonable steps to avoid contact with the products of excluded methods as detailed in their approved organic system plan, the unintentional presence of the products of excluded methods should not affect the status of an organic product or operation.[19]

The NOP calls for testing only if there is "reason to believe" that a grower has used excluded methods.[20] The preamble states that a "reason to believe" may be triggered by situations such as a formal, written complaint to the certifying agent regarding the practices of a certified organic operation; the proximity of a certified organic operation to a potential source of drift; or the product from a certified organic operation being unaffected when neighboring fields or crops are infested with pests.[21]

This testing provision does not establish a zero tolerance standard for the presence of products of excluded methods in organically labeled food. Rather, it serves as a warning that excluded methods may have been used: "Any detectable residues of . . . a product produced using excluded methods found in or on samples during analysis will serve as a warning indicator to the certifying agent."[22]

> [T]hese regulations do not establish a "zero tolerance" standard. . . [A] positive detection of a product of excluded methods would trigger an investigation by the certifying agent to determine if a violation of organic production or handling standards occurred. The presence of a detectable

[19] 65 Fed. Reg. at 80556.
[20] 7 C.F.R. § 205.670(b).
[21] *See* 65 Fed. Reg. at 80629.
[22] *Id.* at 80628.

> residue alone does not necessarily indicate use of a product of excluded methods that would constitute a violation of the standards."[23]

Only if the organic producer intentionally used excluded methods of crop production will that producer be subject to suspension or revocation of organic certification. There is no evidence that any organic grower has lost certification due to unintended presence of GE material.

1.5.1 Non-GMO Project Working Standard

The Non-GMO Project is a non-profit organization created by leading players in the organic industry to "offer consumers a consistent non-GMO choice for organic and natural products that are produced without genetic engineering or recombinant DNA technologies" (Non-GMO Project, 2010a). The Non-GMO Project has created a working standard to implement its goal. The standard sets action thresholds for "GMO" (GE) adventitious presence for certain products. If these action thresholds are exceeded, the participant must investigate the cause of the exceedance and take corrective action (Non-GMO Project, 2010, p. 13). The standard sets a threshold of 0.25% for GE material for the presence of GE traits in non-GE seeds (p. 28), and a 0.9% threshold for non-GE food or feed (p.14).

1.5.2 Growth in organic and GE farming

Expansion of organic farming has succeeded at the same time as the growth of GE crops. Consumer demand for organically produced goods "has shown double-digit growth for well over a decade" and organic products "are now available in nearly 20,000 natural food stores and three of four conventional grocery stores." Organic products "have shifted from being a lifestyle choice for a small share of consumers to being consumed at least occasionally by a majority of Americans" (USDA ERS, 2009c).

1.6 COEXISTENCE IN US AGRICULTURE

1.6.1 Coexistence and biotechnology

Coexistence of different varieties of sexually compatible crops has long been a part of agriculture, especially in seed production, where large investments are made in developing new varieties and high seed purity levels are required by the Federal Seed Act implementing regulations.[24] The aspect of coexistence most relevant to this document is that related to specific methods of crop production. In this context, coexistence refers to the "concurrent cultivation of conventional, organic, and genetically engineered (GE) crops consistent with

[23] *Id.* at 80632.
[24] 7 CFR § 201

underlying consumer preferences and choices" (USDA Advisory Committee, 2008). The differences among these crops that are particularly relevant to coexistence in this ER are in the types of breeding methods (sometimes referred to as "genetic modifications") that are associated with each of the three types of crops.

"**Genetic engineering**" is defined by APHIS regulations as "the genetic modification of organisms by recombinant DNA techniques."[25] Recombinant DNA (rDNA) techniques are discussed in Section 3.1.1 of this ER. While there are many ways to genetically modify a crop, the APHIS definition of GE crops applies only to those developed using rDNA techniques, which are among the more modern breeding methods.

Organic crops are those produced in accordance with the requirements of the NOP, discussed in Section 1.5.

Conventional crops are simply those that are neither GE nor organic. They may be commodity crops (mass produced), or they may be identity preserved, with some characteristic tailored for a specific end user. Identity-preserved usually refers to a "specialty, high-value, premium or niche market" (Massey, 2002). One type of identity preserved product that has been produced since the introduction of GE crops is "non-GE;" however, there are no mandatory standards governing the use and/or marketing of "non-GE" products (USDA Advisory Committee, 2008).

Farmers who want to maximize their profitability must decide whether the higher prices (premiums) they may receive for organic or identity-preserved crops are sufficient to offset the added managerial costs of producing these crops. As researchers have noted, "Although yields on organic farms are sometimes less than those of conventional systems, price premiums make it an attractive option for growers looking for specialized markets and a higher-value product" (Ronald and Fouche, 2006). There is such a niche market for organic red beets and organic Swiss chard. However, no premium or niche market exists for either conventional or organic sugar beets.

1.6.2 USDA position on coexistence and biotechnology

It is USDA's position that all three methods of agricultural production described above can provide benefits to the environment, consumers, and the agricultural economy (Smith, 2010b).

[25] 7 CFR §340.1

1.6.3 Coexistence in US crop production

Since the time GE crops were introduced in the US in the mid-1990s, organic markets have grown and expanded (Smith, 2010b, p. 10).

The USDA Advisory Committee on Biotechnology and 21st Century Agriculture who reported that "coexistence among the three categories of crops is a distinguishing characteristic of U.S. agriculture, and makes it different from some other parts of the world," expressed its belief that US agriculture supports coexistence, and recommended continued government support of coexistence (USDA Advisory Committee, 2008). Among the Committee's findings:

- The U.S. is the largest producer of GE crops in the world.
- The U.S. is one of the largest producers of organic crops in the world.
- The U.S. is one of the largest exporters of conventionally-grown, identity preserved, non-GE crops in the world.
- Some U.S. farmers currently are producing a combination of organic, conventional, and GE crops on the same farm.

Among the coexistence-enabling factors the Committee identified are the existing "legal and regulatory framework that has enabled different markets to develop" without foreclosing the ability of "participants in the food and feed supply chain to establish standards and procedures (e.g., not setting specific mandatory adventitious presence (AP) thresholds and having process-based rather than product-based organic standards)." At the same time, development of practices and testing methods that allow for voluntary thresholds has also enabled coexistence (USDA Advisory Committee, 2008).

As APHIS has previously observed, "studies of coexistence of major GE and non-GE crops in North America and the European Union (E.U.) demonstrated that there has been no significant gene flow from GE crops and that GE and non-GE crops are coexisting with minimal adverse economic effects" (Smith, 2010b, pp. 11-12) (citing Gealy et. al, 2007; Brookes and Barfoot, 2003; Brookes and Barfoot, 2004(a) and (b), and Walz 2004)). In addition, "the agricultural markets and local entities have addressed coexistence through contractual arrangements, management measures, and marketing arrangements. This market-based approach to coexistence has created economic opportunities for all kinds of producers of agricultural products." (*Id.* p. 9). RRSB is one of fifteen glyphosate-tolerant events previously deregulated by USDA. *See* APHIS, EPA, Petitions of Non-Regulated Status Granted or Pending by APHIS as of February 2, 2010, http://www.aphis.usda.gov/brs/not_reg.html.

1.7 ROLE OF THE NATIONAL ACADEMIES IN AGRICULTURAL BIOTECHNOLOGY

The analyses in this ER are based on published, peer-reviewed scientific papers; federal government assessments; assessments from international agencies; information from specialists from many universities; data collected by Monsanto/KWS under controlled conditions; and information from other relevant sources. One resource used for this ER is the National Academies (NA), a private, non-profit institution that advises the nation on scientific and technical matters. It consists of the National Academy of Sciences (NAS), the National Academy of Engineering, the Institute of Medicine (IM) and the National Research Council (NRC) (NA, 2010). Scientists, engineers and health professionals are elected by their peers to the academy and serve *pro bono.* Reports are prepared by committees of members with specialized expertise and reviewed by outside anonymous experts (Alberts, 1999).

The NA has been active in studies related to agricultural biotechnology since the 1970s, works cooperatively with federal agencies, and its reports have provided guidance and recommendations for process improvement to regulatory agencies (Alberts, 1999). The NRC 1989 guidelines for field testing of genetically engineered organisms were used as the basis for agency procedures for field trials (Alberts, 1999; NRC, 1989). In studies in 1987 and 2000 the NRC emphasized that the characteristics of the modified organism should be the object of a risk assessment, and not the methods by which the modifications were accomplished; and that the risks associated with recombinant DNA techniques are the same in kind as risks from other types of genetic modification (NRC, 1987; NRC, 2000). This position was re-iterated in a 2004 study prepared jointly by the IM and the NRC. Whether such compositional changes result in unintended health effects is dependent on the nature of the substances altered and the biological consequences of the compounds. To date, "no adverse health effects attributed to genetic engineering have been documented in the human population" (IM/NRC, 2004, p. 8). In a 2002 report, the NRC "found that the current standards used by the federal government to assure environmental safety of transgenic plants were higher than the standards used in assuring safety of other agricultural practices and technologies" (NRC, 2002). The NRC reports that, while biotechnology is not without risk, since the first commercial introduction of transgenic plants, "biotechnology has provided enormous benefits to agricultural crop production" (NRC, 2008). NRC's latest report on biotechnology in agriculture evaluates the impact of genetically engineered crops on farm sustainability. The authors concluded that an understanding of impacts on all farmers will help ensure that GE technology contributes to sustainability and that

commercialized GE traits to date, when used properly, "have been effective at reducing pest problems with economic and environmental benefit to farmers" (NRC, 2010).

1.8 ALTERNATIVES CONSIDERED

In addition to the alternative of partial deregulation or other administrative action implementing the interim conditions (Alternative 2), this ER considers the alternative of full regulation (Alternative 1).

1.8.1 Alternative 1 – No Action (full regulation)

In conducting NEPA review, agencies consider a No Action alternative, which provides a baseline against which action alternatives can be evaluated. This ER identifies the No Action alternative as a return to full regulation – or the *status quo* existing when the petition for deregulation of event H7-1 was initially submitted. Under this alternative, the introduction of event H7-1 lines of glyphosate tolerant sugar beets would be fully regulated and would require permits issued or notifications acknowledged by APHIS until APHIS completes its EIS and issues a Record of Decision (ROD) regarding whether to deregulate H7-1 lines of glyphosate tolerant sugar beets. For purposes of this analysis, we assume that Alternative 1 would not involve widespread event H7-1 sugar beet cultivation, and instead would contemplate a return to conventional sugar beet crops or to crops other than sugar beet. *Note*: As indicated above, the *status quo* is event H7-1 sugar beets comprising 95 percent of the U.S. sugar beet crop.

1.8.2 Alternative 2 – Partial Deregulation with Interim Conditions

Under this alternative, the introduction of event H7-1 lines of glyphosate tolerant sugar beets would be allowed under interim conditions until APHIS completes its EIS,, issues a Record of Decision, and that decision takes effect – currently anticipated for mid-2012 (Smith, 2010b, p. 8).

This section describes the affected environment and provides other contextual information for an understanding of the environmental consequences analyzed in Section 3.

2.1 SUGAR BEET CHARACTERISTICS AND USES

Sugar beet (*Beta vulgaris L.*) is a biennial plant that was developed in Europe in the 18th century from white fodder (animal feed) beets. Sugar reserves are stored in the sugar beet root during the first growing season for an energy source during overwintering. The roots are harvested for sugar at the end of the first growing season but plants that overwinter in a mild climate will produce flowering stems and seed during the following summer and fall. Sugar beet roots will not survive the winter in any of the growing regions except California (Cattanach et al, 1991).).

Pollination. The sugar beet is cross-pollinated (pollination occurs between plants rather than within single plant) by wind (Cattahach et al, 1991).

Climate. Sugar beets have adapted to a very wide range of climatic conditions. Sugar beets primarily are a temperate zone crop produced in the Northern Hemisphere at latitudes of 30 to 60°N. The sugar beet plant grows until harvested or growth is stopped by a hard freeze. Sugar beets primarily grow tops until the leaf canopy completely covers the soil surface in a field. This normally takes 70 to 90 days from planting. Optimal daytime temperatures are 60 to 80°F for the first 90 days of plant growth. Regions with long day length are most suitable for sugar beet growth. The most favorable environment for producing a sugar beet crop from 90 days after emergence to harvest is bright, sunny days with 65 to 80°F temperatures followed by nighttime temperatures of 40 to 50°F. These environmental conditions maximize yield and quality in a sugar beet crop. Sugar beets are successfully produced under irrigation in areas with very low rainfall and in regions relying on natural rainfall (Cattanach et al, 1991).

Products. Sugar beets contain from 13 to 22 percent sucrose. Sugar beet pulp and molasses are processing by-products used as feed supplements for livestock. These products provide required fiber in rations and increase the palatability of feeds. Molasses by-products from sugar beet processing are used in the alcohol, pharmaceuticals, and bakers' yeast industries (Cattanach et al, 1991).

2.2 ACCEPTANCE OF EVENT H7-1 SUGAR BEETS

Event H7-1 sugar beets were first available for commercial production in 2007 (Lilleboe, 2008). In the 2009/10 crop year, event H7-1 varieties accounted for about 95 percent of planted area, up from about 60 percent in 2008/09 (USDA ERS, 2009a). Since, as noted in Section 1, no event H7-1 sugar beets have been grown in California and California represents approximately 3 percent of US sugar beet production (Table 2-1), 98 percent of the planted 2009/2010 sugar beet crop in the remaining US sugar beet regions was event H7-1.

Table 2-1. US Sugar Beet Production, 2009/2010 Season

Region/State	1,000 short tons	Percent of US Total
Great Lakes		
Michigan	3,318	
Total	3,318	11
Upper Midwest		
Minnesota	10,641	
North Dakota	4,796	
Total	15,437	52
Great Plains		
Colorado	963	
Montana	1,001	
Nebraska	1,294	
Wyoming	678	
Total	3,936	13
Northwest		
Idaho	5,591	
Oregon	395	
Total	5,986	20
Far West		
California	886	
Total	886	3

Source: USDA ERS, 2010a, Table 14

2.3 SUGAR BEET ROOT PRODUCTION

2.3.1 US Production by regions

The US is among the world's largest sugar producers. Unlike most other producing countries, the US has both large and well-developed sugarcane and sugar beet industries. Since the mid-1990s, sugarcane has accounted for about 45 percent of the total sugar produced in the US, and sugar beets for about 55 percent of production. Since 1961, planted sugar beet acreage has fluctuated within the range of 1.1 million (low in 1982) to 1.6 million (high in 1975) (USDA NASS 2010a). Annual cash receipts for sugar beets in the US in the past few years have ranged up to $1.5 billion (USDA ERS, 2009b).

Figure 2-1 shows the five major US sugar beet producing regions, along with 2008 production by county.

Great Lakes. Great Lakes sugar beet production, now entirely in Michigan, occurs in the flat area around Saginaw Bay. Sugar beets grown in the Great Lakes region do not require irrigation. The Great Lakes region also includes Ohio, where sugar beets were last produced in 2004.

Upper Midwest. The Upper Midwest is the largest sugar beet production region in the US, with the majority of this production in the Red River Valley. The Red River flows north into Canada and forms most of the North Dakota-Minnesota border. It flows through a broad, flat valley formed by an ancient glacial lake. The Minnesota River Valley, another broad, flat glacial valley that crosses southern Minnesota and is almost continuous with the Red River Valley, is also a large production area. Irrigation is uncommon in the Red River/Minnesota River Valleys (Ali, 2004). There is another, much smaller Upper Midwest production area along the Montana border of North Dakota, in the valley of the Yellowstone River and its tributaries.

Great Plains. The Northern Great Plains region includes production areas in northern Wyoming and southern Montana. The major sugar beet growing areas in the Northern Great Plains are the sandy loam soils along the Yellowstone River and its tributaries (Mikkelson and Petrof, 1999, p. 2). The Southern Great Plains subregion includes growing areas in western Nebraska, southeastern Wyoming and northeastern Colorado, primarily in the valley of the Platte River and its tributaries. All Great Plains sugar beet production requires irrigation (Thomas et al, 2000, p. 1; Mikkelson and Petrof, 1999, p. 3; McDonald et al, 2003, p. 2).

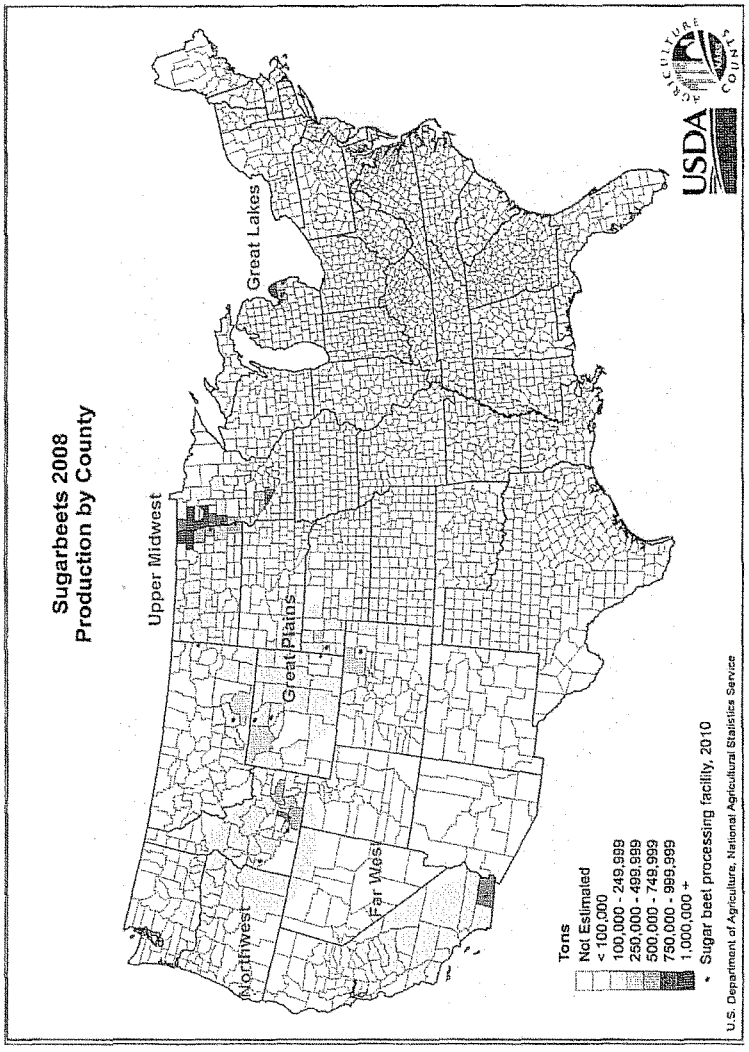


Figure 2-1. US sugar beet regions and 2008 county production.

The Great Plains region previously included New Mexico and Texas, where sugar beets were last harvested in 1997.

Northwest. Most production in the Northwest region is in the sandy loam soil of the Snake River Valley in Idaho. This area also requires irrigation (Traveller and Gallian, 2000, p. 1). In addition, production occurs in southeast Washington state, east of the Cascade mountains.

Far West (California). The only sugar producing area in California is in the Imperial Valley in the far southern end of the state, where the only remaining sugar processing plant in California exists. Production occurred in the Central Valley (near the middle of the state) through 2008; however, the last processing plant in this area closed in 2008. As recently as the 1990s, nearly 30 percent of sugar beet production was in the Central Valley; there were also small areas of production in coastal counties (but production in those regions no longer exist) (California Beet Growers Association, 1998, p.1).

US production for the 2009/2010 season (harvested in 2009 and processed in 2009/2010) is shown in Table 2-1. In 2010, sugar beet was planted on 1.2 million acres (USDA ERS, 2010a, Table 14). Sugar beet production by county from 2005 to 2008, including acres planted, acres harvested, yield per acre, total yield and sucrose percent, is tabulated in Appendix D.

The distribution of planted acreage by state is shown in Figure 2-2.

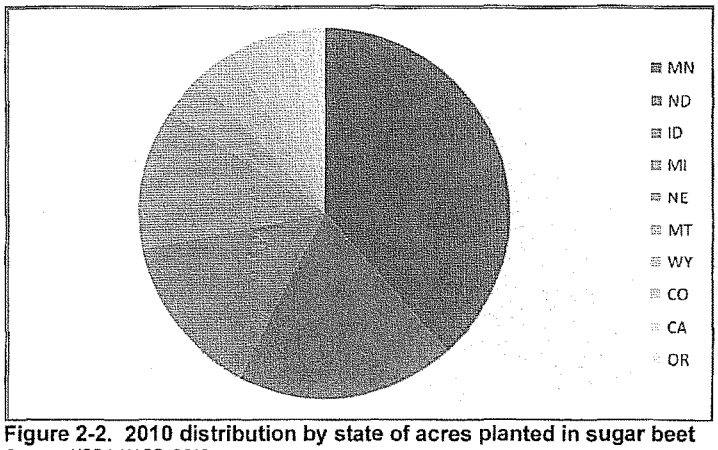


Figure 2-2. 2010 distribution by state of acres planted in sugar beet
Source: USDA NASS, 2010a

2.3.2 Grower-processor relationships

Sugar beet production, more than most crops, requires close coordination between the grower and the processor. The crop is of little value without a processor to extract the sugar, and a sugar processing facility cannot stay in business without a reliable supply of beets (Kaffka and Hills, 1994, p. 2). While a type of syrup can be made on a small scale, home garden production of sugar would be impractical; processing cannot be duplicated successfully in a home kitchen (California Beet Growers Association, 1998, p. 3). Sugar beets are 75 percent water and expensive to transport long distances (Michigan Sugar Company, 2010a). For economic reasons, sugar beets are typically grown within 60 miles of a processing facility, but may be grown up to 100 miles away (Western Sugar Cooperative, 2006a). Locations of the 22 processing facilities in operation in 2010 are shown in Figure 2-2. While existing facilities have been upgraded, no new currently operating processing facilities have been built in the US since 1975. An estimated cost for an average-sized new facility in 1991 was $100 million (Cattanach et al, 1991, p. 16). The cost would be substantially higher today due to inflation and other factors.

Sugar beet production and processing in the US is done almost entirely by grower-owned cooperatives. The cooperatives own the processing facilities and the sugar beet farmers are members of the cooperatives. The members own shares of stock that require them to grow a specified acreage of beets in proportion to their stock ownership in the cooperative and guarantee processing for their beets. US companies are summarized by regions below. Cooperatives are owned by growers who are principally family farmers. According to the 2007 US Census of Agriculture, over 4,000 farms grow sugar beets (USDA ERS 2009b).

Great Lakes. Michigan Sugar Company, the third-largest sugar beet processor in the US, processes all the sugar beets in the Great Lakes region, as well as beets from Ontario, Canada.. The cooperative has over 1,000 grower-shareholders who grow sugar beets on 150,000 acres each year. The sugar beets are processed into sugar at factories in Bay City, Sebewaing, Caro and Croswell. The cooperative employs 450 year-round and 1,200 seasonal employees, generates nearly $400 million in direct economic activity annually in the local communities in which it operate, and annually produces nearly one billion pounds of sugar (Michigan Sugar Company, 2010b).

Upper Midwest. Three cooperatives operate in the Upper Midwest. American Crystal Sugar Company, the largest sugar beet producer in the US, is owned by approximately 3,000

shareholders who raise 500,000 acres of sugar beets in the Red River Valley of Minnesota and North Dakota. The company operates five sugar processing facilities in the Red River Valley: three in Minnesota (Crookston, East Grand Forks and Moorhead) and two in North Dakota (Drayton and Hillsboro). American Crystal also operates a sugar beet processing facility in eastern Montana at Sidney, under the name Sidney Sugars Incorporated. American Crystal's fiscal year 2009 Red River Valley crop averaged 25.4 tons per acre with 17.6 percent sugar content.. In 2009, the company produced approximately 3 billion tons of sugar and 681,000 tons of agri-products (molasses and pulp) (American Crystal Sugar Company, 2009). Minn-Dak Farmers Cooperative, with 450 shareholders, operates a processing facility in Wahpeton, in the far southeast corner of North Dakota. Minn-Dak also operates a yeast factory, which uses molasses from sugar beet processing (Minn-Dak Farmers Cooperative, undated). The Southern Minnesota Beet Sugar Cooperative has approximately 600 shareholders who farm 120,000 acres, and operates a processing facility near Renville, Minnesota (Southern Minnesota Beet Sugar Cooperative, 2010).

Great Plains. The Western Sugar Cooperative, with 135,000 acres and five factories, processes most of the Great Plains sugar beet. Processing facilities are in Fort Morgan, Colorado; Billings, Montana; Scottsbluff, Nebraska; and Lovell and Torrington, Wyoming. Wyoming Sugar Beet Company, LLC is not a cooperative, but works through the Washakie Farmers Cooperative to acquire beets for its plant in Worland, Wyoming (Boland, 2003).

Northwest. The Amalgamated Sugar Company LLC processes all the sugar beet in the Northwest region. Amalgamated is owned by Snake River Sugar Company, a grower-owned cooperative, and is headquartered in Boise, Idaho with processing plants in Paul, Twin Falls, and Nampa, Idaho (Snake River Sugar Company, 2009).

Far West (California). Spreckels Sugar Company, a subsidiary of Southern Minnesota Beet Sugar Cooperative, operates a sugar beet processing facility in Brawley, California, in the Imperial Valley. Yields in the Imperial Valley are higher than anywhere else in the US, averaging approximately 40 tons per acre (Spreckels Sugar, 2009).

Tillage systems *are defined by the amount of crop residue remaining on the soil.*

Conventional tillage *systems leave less than 30 percent of crop residue remaining on the soil when planting another crop.*

Conservation tillage *leaves 30 percent or more of the previous crop residue covering the soil when planting another crop.*

Reduced tillage *leaves 15 to 30 percent of the previous crop residue covering the soil when planting another crop.*

Mulch tillage *disturbs the soil prior to planting. Tillage tools such as chisels, field cultivators, disks or blades are used. Weed control is accomplished with herbicides and/or cultivation.*

No Till *leaves the soil undisturbed.*

With ***strip tillage****, a specific type of conservation tillage, tillage is confined to narrow strips where seeds will be planted. Strip tillage is usually done in the fall. The loosened soil creates a ridge 3 to 4 inches high, which improves soil drainage and warming. By spring, it usually settles down to 1 or 2 inches high, and after planting the field is flat.*

Sources: Ali, 2004, p. 32;

2.3.3 Sugar beet cultivation practices

Seed bed preparation and tillage. The objectives of seedbed preparation are to manage crop residue (the leftover vegetative matter from the previous crop), minimize erosion, improve soil structure, and eliminate early season weeds. Tillage, which can be done in fall and spring, can help improve soil structure and eliminate early weeds, but tillage can also increase erosion. No-till, strip tillage in previous crop residues, and other conservation tillage systems (see definitions at left) require more planning and better management (Cattanach et al, 1991). In addition to the reduced tillage methods (noted at left), no-till productions systems do not have any associated tillage where weed control is entirely through chemical means. A survey conducted in 2000, before event H7-1 sugar beets were available, found that use of conventional tillage for sugar beet production varied by region from 64 percent of acreage in the Red River Valley in the Upper Midwest to 96 percent of acreage in the Northwest (California was not included because there was too little data). Growers in the Red River Valley reported using reduced tillage on 16 percent of sugar beet acres and mulch tillage on 20 percent (Ali, 2004). Because weeds can be effectively controlled with glyphosate applications, event H7-1 sugar beets may be grown with less tillage (NRC, 2010, p. 6; Duke and Cerdeira, 2007, p. 3; Wilson, 2009).

In the Idaho (Northwest), prior to glyphosate tolerant sugar beets conventional tillage was essential for weed control, minimizing soil erosion and improving soil structure (Ali, 2004; Traveller and Gallian, 2000, p. 1). Since the introduction of event H7-1, some farmers in the Northwest have switched to strip tillage and have reported reduced fuel and labor costs and

reduced wind erosion (Lilleboe, 2008). Researchers in Idaho found that while conventional tillage was necessary for weed control with conventional beets, the practice has little to no benefit with glyphosate-tolerant sugar beets (Miller and Miller, 2008).

In much of the Great Plains region, conventional sugar beets were cultivated using conservation tillage systems; however, deep tillage, which is used to improve drainage, was utilized to help reduce the risk of soil borne diseases (mainly the beet necrotic yellow vein virus causing rhizomania) (McDonald et al, 2003, p.2). Farmers in the Great Plains have reported that strip tilling and event H7-1 have "been a great marriage," with strip tilling resulting in reduced wind erosion, reduced irrigation requirements and fuel and time savings (Lilleboe, 2010).

Michigan Sugar Company recommends conservation tillage practices to help control erosion resulting from strong early spring wind in the Great Lakes region (Michigan Sugar Company, 2009, p. 2). However, since the introduction of the event H7-1 this growing region has the option of implementing varying methods of reduced tillage systems.

Recent studies by North Dakota State University have found that since the introduction of event H7-1, strip tillage is a viable option for sugar beet production that reduces fuel and fertilizer costs and susceptibility to wind erosion (Overstreet et al, 2009). A member of the Minn-Dak Farmers Cooperative, who farms about 1,100 acres of sugar beets annually, has found that instead of three post-emergence tillage trips across the fields, with event H7-1 he now needs "little to no tillage post-emergence" (Mauch, 2010, p. 3).

Planting and harvesting times. In all regions except the Far West (California), sugar beet root crops are planted in early spring (March through May, depending on latitude and location) and harvested in fall (September through November, also varying with regions) (McDonald et al, 2003; Mikkelson and Petrof, 1999, p 3; Michigan Sugar Company, 2010b).

In the Imperial Valley in California, sugar beets are planted in September and October and harvested from April to July (California Beet Growers Association, 1999, p. 1).

Crop rotations. Sugar beets tend to be grown with other crops in three- to five-year rotations, although sometimes two years is used. The rotation results in improved soil fertility, fewer problems with diseases, and improved yields and quality of beets. The impact of certain soil borne diseases, nematodes (parasitic, microscopic worms) and weeds are minimized through

crop rotations (Mikkelson and Petrof, 1999, p. 3; USDA ERS, 2009b, p. 2; Hirnyck et al, 2005, p. 13).

To assess the likelihood that the rotational crops planted after event H7-1 sugar beet would be another glyphosate-tolerant crop an analysis of rotations to other crops was conducted and included in the petition (Schneider, 2003, Table VII-13). This rotational crop table has been updated with crop information from the 2007 planting season and includes projected acreage for recently commercialized glyphosate-tolerant crops (Table 2-2).

2.3.4 Sugar beet bolters and volunteers

Bolting. Sugar beet, if left to grow in a temperate climate, is a biennial plant that produces an enlarged root the first year and flowers in the second year. Typically, the plant is induced to flower through a process called vernalization that occurs during prolonged exposure to cooler temperatures. Occasionally sugar beets will bolt (produce a seed stalk that may ultimately flower) in their first year of production; however, with breeding, bolting tendency has been reduced. Much effort has gone into producing sugar beets that resist bolting, and today's varieties show little bolting (OECD, 2001, p. 15). No difference in bolting characteristics would be expected between conventional and event H7-1 sugar beets, as the introduction of the glyphosate tolerant trait does not affect the bolting characteristics of the sugar beet. In the 2000-2001 variety field trials with lines containing event H7-1 reported in the petition, six of 12 event H7-1 sugar beet varieties had 0.00 percent bolters; for those varieties with bolters, the percentages were 0.03 percent for three; 0.06 percent for two, and 0.19 percent for one. All entries were established as six row plots forty feet in length with six replications at each location in 2000, and four replications at each location in 2001 (Schneider, 2003, Table VI-9). Darmency et al report bolting percents now as low as 0.01 percent (2009, p. 1090). While Darmency et al were referring to conventional sugar beets, event H7-1 would not affect bolting characteristics, and breeders continue to select for low rates of bolting.

For bolting to occur, the plants first require exposure to temperatures around 40 to 42 degrees F (others report 34 to 39 degrees F in the 4 to 5 leaf stage; conditions are variety-dependent), followed by exposure to increasing day length (12 hours or more). Varieties differ in their sensitivity to bolting, with easy bolting lines requiring only a few to 1000 hours of exposure to low temperatures, while bolting-resistant lines may require 2000 hours or more. Beets can de-vernalize when exposed to high temperatures (OECD, 2001, p. 15).

Bolting depletes the root of simple sugars, translocating this stored energy into the above-ground biomass, making the root woody and worthless as a source of sugar. Bolters are taller than the rest of the crop. Thus, bolters are effectively weeds within a sugar beet field. The woody roots that result from bolters can damage harvesting and processing equipment (Ellstrand, 2003, p. 5-7). For these reasons, growers remove bolters. A bolter is evident in a field weeks before the seed stalk would flower to produce pollen or seed. Thus, stewardship can be 100% successful in eliminating any small probability of flowering.

Table 2-2. Rotational crops following US sugar beet production and an estimation of rotational crops as Roundup Ready® crops (all acreages are expressed as 1000 acres)

A	B	C	D	E	F	G	H	I	J	K
State	Total Sugar Beet Acres[1]	Major Crops That Follow Sugar Beet In Rotation[2]	Total Acreage of Rotation Crop in States[1]	Percent of Rotational Crop Rotated Following Sugar Beet[3]	Rotational Crop Acres Following Sugar Beet[3]	Percent Rotational Crop of Total Sugar Beet[4]	Percent Roundup Ready® Rotational Crop Option[5,6]	Acreage of Roundup Ready® Rotational Crop Option[7]	Percent of Sugar Beet Acres Preceding Major Rotations[4]	Estimated Percentage of Roundup Ready® Crops as Major Rotations[5]
CA	50	Barley	130	7.7%	10	20%	NA	0		
		Dry Beans	92	5.4%	5	10%	NA	0		
		Durum	95	10.5%	10	20%	NA	0		
		Oats	260	3.8%	10	20%	NA	0		
		Spring Wheat	530	2.8%	15	30%	NA	0		
			Total: 1,107		**Total: 50**			**Total: 0**	**4.52%**	**0%**
CO	44	Barley	85	5%	4	10%	NA	0		
		Corn	1200	3%	31	70%	52%	16		
		Dry Beans	92	8%	7	15%	NA	0		
		Potato	78	3%	2	5%	NA	0		
			Total: 1,455		**Total: 44**			**Total: 16**	**3.02%**	**1.10%**
ID	212	Alfalfa	730	1.5%	11	5%	50%	6		
		Barley	730	4.4%	32	15%	NA	0		
		Corn	190	3.2%	6	3%	52%	3		
		Dry Beans	95	4.2%	4	2%	NA	0		
		Spring Wheat	530	30.0%	159	75%	NA	0		
			Total: 2,275		**Total: 212**			**Total: 9**	**9.32%**	**0.40%**
MI	180	Corn	2,250	5.2%	117	65%	52%	61		
		Dry Beans	270	6.7%	18	10%	NA	0		
		Soybean	2,050	2.2%	45	25%	91%	41		
			Total: 4,570		**Total: 180**			**Total: 102**	**3.94%**	**2.23%**
MN	505	Barley	210	23.8%	50	10%	NA	0		
		Soybean	7,200	4.9	354	70%	91%	322		
		Spring Wheat	2,000	5.1%	101	20%	NA	0		
			Total: 9,410		**Total: 505**			**Total: 322**	**5.37%**	**3.42%**

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Table 2-2. Rotational crops following US sugar beet production and an estimation of rotational crops as Roundup Ready® crops (all acreages are expressed as 1000 acres)

A	B	C	D	E	F	G	H	I	J	K
State	Total Sugar Beet Acres[1]	Major Crops That Follow Sugar Beet In Rotation[2]	Total Acreage of Rotation Crop In States[1]	Percent of Rotational Crop Rotated Following Sugar Beet[2]	Rotational Crop Acres Following Sugar Beet[2]	Percent Rotational Crop of Total Sugar Beet[4]	Percent Roundup Ready® Rotational Crop Option[5,6]	Acreage of Roundup Ready® Rotational Crop Option[7]	Percent of Sugar Beet Acres Preceding Major Rotations[8]	Estimated Percentage of Roundup Ready® Crops as Major Rotations[9]
MT	58	Barley	1,200	2.4%	29	50%	NA	0		
		Corn	65	21.5%	14	25%	52%	7		
		Dry Beans	27	33.3%	9	15%	NA	0		
		Spring Wheat	3,750	0.2%	6	10%	NA	0		
			Total: 5,042		**Total: 58**			**Total: 7**	**1.15%**	**0.14%**
ND	265	Barley	1,600	2.5%	40	15%	NA	0		
		Corn	1,230	3.3%	40	15%	52%	21		
		Durum	2,100	0.6%	13	5%	NA	0		
		Soybean	2,670	4.0%	106	40%	91%	96		
		Spring Wheat	6,900	1.0%	66	25%	NA	0		
			Total: 14,500		**Total: 265**			**Total: 117**	**1.83%**	**0.81%**
NE	57	Corn	8,400	0.3%	29	50%	52%	15		
		Dry Beans	185	11.9%	22	40%	NA	0		
		Winter Wheat	1,650	0.4%	6	10%	NA	0		
			Total: 10,235		**Total: 57**			**Total: 15**	**0.56%**	**0.15%**
WY	40	Barley	90	24.4%	22	55%	NA	0		
		Corn	80	12.5%	10	25%	52%	5		
		Dry Beans	32	12.5%	4	10%	NA	0		
		Sugar Beet	40	10%	4	10%	95%	2		
			Total: 242		**Total: 40**			**Total: 7**	**16.53%**	**2.89%**
Overall	1,411	Alfalfa	730	1.5%	11	0.8%	50%	6		
		Barley	4,045	4.6%	186	13.2%	NA	0		
		Corn	13,415	1.8%	247	17.5%	52%	128		
		Dry Beans	793	8.7%	69	4.9%	NA	0		

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Table 2-2. Rotational crops following US sugar beet production and an estimation of rotational crops as Roundup Ready® crops (all acreages are expressed as 1000 acres)

A	B	C	D	E	F	G	H	I	J	K
State	Total Sugar Beet Acres[1]	Major Crops That Follow Sugar Beet In Rotation[2]	Total Acreage of Rotation Crop In States[1]	Percent of Rotational Crop Rotated Following Sugar Beet[3]	Rotational Crop Acres Following Sugar Beet[4]	Percent Rotational Crop of Total Sugar Beet[4]	Percent Roundup Ready® Rotational Crop Option[5,6]	Acreage of Roundup Ready® Rotational Crop Option[7]	Percent of Sugar Beet Acres Preceding Major Rotations[8]	Estimated Percentage of Roundup Ready® Crops as Major Rotations[9]
		Durum	2195	1.0%	23	1.6%	NA	0		
		Oats	260	3.8%	10	0.7%	NA	0		
		Potato	78	2.6%	2	0.1%	NA	0		
		Soybean	11,920	4.2%	505	35.8%	91%	460		
		Spring Wheat	13,710	2.5%	347	24.6%	NA	0		
		Sugar Beet	40	10%	4	0.3%	95%	2		
		Winter Wheat	1,650	0.4%	6	0.4%	NA	0		
State Totals			**Total: 48,836**		**Total: 1,411**			**Total: 596**	**2.89%**	**1.22%**

Legend:

NA denotes not applicable.

1 Acreage planted of the specific crop is based on 2002 planting data (USDA-NASS, 2003).

2 Rotated crops and acreage following sugar beet production are based on communications from individual local experts, i.e., university agronomists, USDA-ARS and Monsanto field personnel.

3 Column E obtained by dividing Column F by Column D and multiplying by 100.

4 Column G obtained by dividing Column F by Column B and multiplying by 100.

5 Roundup Ready® rotational crop penetration rates for corn and soybean are based on 2007 plantings (USDA-NASS, 2007); penetration rates for alfalfa are assumed to be 50% for the purpose of this assessment to represent potential future plantings.

6 Roundup Ready® rotational crop penetration rates for corn and soybean are based on 2007 plantings (USDA-NASS, 2007); penetration rates for sugar beet are assumed to be 95% for the purpose of this assessment to represent potential future plantings.

7 Column I obtained by multiplying Column F by Column H.

8 Column J obtained by dividing Column B by Column D Total and multiplying by 100.

9 Column K obtained by dividing Column I Total by Column D Total and multiplying by 100.

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In the Imperial Valley in California, sugar beets are planted in September, grow through the winter months, and are harvested the following April through June. Vernalization occurs more frequently in the Imperial Valley than in the other US regions, where sugar beet is planted in the spring and harvested in the fall. If the winter in the Imperial Valley is unusually cold and harvesting is delayed, some bolters can develop (California Beet Growers Association, 1998, pp. 3-5; Bartsch et al, 2003).

Sugar beet volunteers. Volunteers are plants from a previous crop that are found in subsequent crops. In most crops, volunteers grow from seeds. If sugar beet bolters are allowed to go to seed in certain more temperate climates, the seed may sprout and cause volunteers in later years, in other crops. Groundkeepers are a type of volunteer derived from vegetative tissue (small roots) left in the field after harvest, which can grow in the next season if not controlled.

In most parts of the US where sugar beets are grown, beet roots would not be expected to survive the winter, and therefore groundkeepers would be of little concern (Panella, 2003). Cattanach et al., who focused on production in the northern plains and upper Midwest (including North Dakota and Minnesota), reported that sugar beets could not survive the winter in these areas (1991).

Sugar beets are not good competitors with other crops. Any that survive can be reservoirs for beet diseases and good management practices dictate that they be removed (Kaffka, 1998).

2.4 GENE FLOW

Definition. Gene flow has been defined as the "incorporation of genes into the gene pool of one population from one or more populations" (Futuyma, 1998). Gene flow is a basic biological process in plant evolution and in plant breeding, and itself does not pose a risk (Bartsch et al, 2003; Ellstrand, 2006, p. 116).

How gene flow is addressed in this document. In this section we provide some background information on gene flow, which is included in several different discussions of impacts, as follows:

- Potential for gene flow from event H7-1 sugar beet crops to conventional sugar beet crops (Section 3.3)
- Potential for gene flow from event H7-1 sugar beet to crops to organic sugar beet crops (Section 3.4)
- Potential for gene flow from event H7-1 sugar beet crops to other *Beta* crops (Section 3.5)

- Potential for gene flow from event H7-1 sugar beet crops to other *Beta* seed production areas (Section 3.6)
- Potential for gene flow from event H7-1 sugar beet crops to native beets (Section 3.7)
- Potential for gene flow from event H7-1 sugar beets crops to weed beets (Section 3.8)
- Potential for gene flow from event H7-1 sugar beet to any of the above receptors, in sugar beet seed production (Section 3.9)

Hybridization. In plant biology, when gene flow occurs between individuals from genetically distinct populations and a new plant is formed, the new plant is called a hybrid (Ellstrand, 2003, p. 10). Hybridization is usually thought of as the breeding of closely related species resulting in the creation of a plant that has characteristics different from either parent. Usually this occurs through deliberate human efforts; however, it can also occur indirectly from human intervention, or in nature. For example, when plants are moved to a new environment (with or without human intervention), they may hybridize with plants of a closely related species or subspecies in that new location.

For natural hybridization to occur between two distinct populations, the plants from the two populations must flower at the same time, they must be close enough so that the pollen can be carried from the male parent to the female parent, fertilization must occur, and the resulting embryo must be able to develop into a viable seed that can germinate and form a new plant (Ellstrand, 2003, pp. 11-13).

Introgression. Hybridization may occur in one generation, but in most cases, does not continue on its own. If it does, and stable new populations result, the process is called introgression. For introgression to occur, hybridization of offspring back with the parent types (backcrossing) must occur several times. Because hybrids of distantly related species may not produce viable seed, introgression is much less common than hybridization. For example, in studies done with canola and a weedy relative, backcrossing from the hybrids to the weeds occurred at one-hundredth to one-thousandth the rate of the original hybridization (reported in Stewart, 2008, p. 2). Nevertheless, when weed species are introduced to new areas, there is the potential that those introduced plants may hybridize with other closely related species. Novel hybrids therefore may be created. In addition, novel hybrids may be created through back-crossing (i.e. introgression) with parent species which may change the native species with non-native genetic material. Invasive weeds can result from hybridization events, which mix genetic material potentially producing a wide array of genotypes. Some of these genotypes may exhibit increased invasive properties (USDA ARS, 2008).

Characteristics that favor natural hybridization between two populations when the above requirements are met include (Mallory-Smith and Zapiola, 2008, p. 429):

- Presence of feral populations (domestic populations gone wild) and uncontrolled volunteers
- Presence of a high number of highly compatible relatives
- Self-incompatibility
- Large pollen source
- Large amounts of pollen produced
- Lightweight pollen
- Strong winds (wind pollinated)
- Large insect populations (insect pollinated)
- Long pollen viability

Feral populations are discussed in Section 2.9.4. **Volunteers**, which are plants from a previous crop that are found in a later crop, are common in agriculture and were discussed in Section 3.2.3.

Highly compatible relatives of sugar beets present in the US include red table beets, spinach (or leaf) beets, and Swiss chard (discussed in Sections 3.5, 3.6 and 3.9); and weed beets of the same or closely related species (discussed in Section 3.8).

Sugar beets and other members of the species *B. vulgaris* are **self-incompatible**; that is, fertilization does not occur between the male and female parts on the same plant. Self-incompatible plants must outcross: for fertilization to occur, the pollen from the male part of one plant must be caught by the sticky stigma within the flower of the female part of another plant.

Sugar beets are largely pollinated by **wind** (Mallory-Smith and Zapiola, 2008, Table 1; OECD, 2001, p. 21). The potential for longer-distance gene flow increases with higher wind speeds (Mallory-Smith and Zapiola, 2008, p. 3). Depending on wind conditions, wind-borne sugar beet pollen can be distributed horizontally at least 4,500 meters (2.8 miles) (OECD, 2001, p. 22). However, as discussed in Section 3.9, the vast majority of the pollen does not travel these great distances, and the very small amount that does is unlikely to pollinate another plant.

Successful wind-pollinated flowering plants must produce **large amounts of pollen**: the chances of any single wind-blown pollen grain landing on and being held by the stigma of

another plant are very small. Pollen occurs in "clouds": scientists have estimated sugar beet pollen production at one billion pollen grains per plant (Schneider, 1942, as reported in OECD, 2001, p. 22). There is great competition within this cloud for the limited available ovules (only one each), and the stray pollen from another source has extremely limited opportunity for success. In a large, densely planted area such as a seed production field, pollination is much more likely from the pollen cloud within the field than from stray pollen from another field (Westgate, 2010, p. 3; Hoffman, 2010a, p. 8)).

While pollen can be maintained for longer periods under laboratory conditions, scientists report that sugar beet **pollen viability** under natural conditions is limited to 24 hours (OECD, 2001, p 22; Hoffman, 2010a, p. 8).

2.5 SUGAR BEET WEED MANAGEMENT

This section addresses weed management in sugar beets. Uncultivated wild beets, including feral beets and weed beets, are described in Section 2.9.

2.5.1 Weed characteristics and concerns

While a weed can be defined as any unwanted plant, problem weeds are those that are competitive and persistent within a given cropping system.

Competition for light, water and nutrients. A grower tries to capture the plant resources - primarily light, water, and plant essential nutrients; however, competitive weeds often secure some of these resources for their growth, at the expense of the crop. Some common characteristics of competitive weeds are rapid seedling establishment, high growth rates, prolific root systems and large leaf areas.

Competition for light is probably the most important weed consideration for sugar beets, particularly in irrigated fields, which promote improved growing conditions. Sugar beets ultimately convert solar energy into sucrose, and reduction in light can have a dramatic impact on yields. Thus, weeds that grow taller than sugar beets, especially those with broad leaves, compete with available sunlight that the sugar beet would have used to make sucrose. Barnyardgrass (*Echinochloa crus-galli)*, for example, has broad, flat leaves and can grow up to 5 ft tall, as can Canada thistle (*Cirsium arvense*). Common lambsquarter (*Chenopodium album)* and kochia (*Kochia scoparia)* are fast-growing weeds that can grow to six ft tall and quickly shade sugar beet seedlings. Wild oat (*Avena fatua)* and green foxtail (*Setaria viridis*) grow to heights ranging from approximately 26 to 41 inches. Sugar beet, by comparison, takes months

to reach its final height of approximately 22 inches (Tranel, 2003; McDonald et al, 2003, pp. 9-12; Mesbah et al, 1994, p. 1).

A plant's ability to compete for water is determined largely by the volume of soil the roots occupy. Weeds with large root systems are more likely to be detrimental to sugar beets during periods of water stress. Some perennial weeds can store a multi-year food supply in their roots (Tranel, 2003; McDonald et al, 2003, pp. -12; Mesbah et al, 1994, p. 1).

Plants that develop a root system early in the season have long roots relative to the part of the plant above ground and have high uptake potential can compete successfully for nutrients. Simply applying more fertilizer does not solve the problem and may exacerbate it by stimulating weed growth; weeds often absorb nutrients faster and in greater amounts than sugar beets (Mesbah et al, 1994, p. 1).

Weed persistence. Persistent weeds are able to survive year after year on a given piece of land, in spite of a farmer's efforts to control them. Some plants are both competitive and persistent through the production of large numbers of seeds. The bushy wild proso millet (*Panicum miliaceum*), for example, shatters upon contact when mature, and can produce 400 to 12,000 seeds per square foot. While high reproductive rates also contribute to a weed's persistence, dormancy is the most important trait in persistence. Cultivated soils typically contain thousands of seeds per square meter, waiting for the opportunity to germinate. Some weed seeds, for example, velvetleaf (*Abutilon theophrasti)*, can remain viable in the soil for up to 50 years (McDonald et al, 2003, p. 12). Many perennial weed species have the ability to reproduce from root fragments. Canada thistle, for example, has a deep, spreading root system that can continue to send up shoots after the surface plant has been removed multiple times. Some weeds have the ability to alter their characteristic in response to stress; for example, some weeds respond to drought by flowering and going to seed early (Tranel, 2003; McDonald et al, 2003, pp. 9-12).

2.5.2 Sugar beets and weeds

The sugar beet plant is a poor competitor against weeds, especially from emergence until the sugar beet leaves shade the ground. Emerging sugar beets are small, lack vigor, and take approximately two months to shade the ground. Thus, weeds have a long period to become established and compete. To avoid yield loss from weed competition, weeds need to be controlled within four weeks after sugar beet emergence and weed control needs to be

maintained throughout the season (Cattanach et al, 1991, p. 6; California Beet Growers Association, 1999, p. 25; McDonald et al, 2003, p. 13; Mikkelson and Petrof, 1999, p 19).

Uncontrolled weeds that emerge with the crop may cause from 30 to 100 percent yield losses (California Beet Growers Association, 1999; p. 25; Sprague, 2009). Increasing weed density causes increasing magnitude of yield loss, although the relationship is not linear: a few weeds may not affect yield, and at high weed populations the weeds begin competing with one another. While yield losses are the major concern, weeds create other problems. Late-season weeds can hinder harvesting operations. For example, infestations of wild mustard can cause loss of small beets during harvesting. Many weed species host pathogens (curly top virus), nematodes (sugar beet cyst nematode) and insects (aphids). High levels of weed control are essential for profitable sugar beet production (California Beet Growers Association, 1999; p. 25; Mikkelson and Petrof, 1999, p 19; Mesbah et al, 1994). Prior to adoption of event H7-1 sugar beets, growers regularly used multiple chemical herbicides to attempt to control weeds. (Cole, 2010a, pp. 12-13; Cole, 2010b, pp. 10-14; Kniss, 2010, p. 5; Wilson, 2010a, p. 9; Hoffman, 2010, p. 12).

2.5.3 Problem weeds in sugar beet production

The USDA Agricultural Research Service (ARS) has identified the following weeds as problem weeds in sugar beets that have previously prevented production of maximum yields to conventional crops: kochia (*Kochia scoparia)*, pigweed (*Amaranthus spp.)*, common lambsquarter (*Chenopodium album)*, nightshade (*Solanum spp.)*, common mallow (*Malva neglecta)*, cocklebur *(Xanthium strumarium),* barnyardgrass (*Enchinochloa crus-galli)*, foxtail (*Setaria)*, wild millet (*Panicum miliaceum)*, wild oats (*Avena fatua)*, sowthistle (*Sonchus L.)*, Canada thistle (*Cirsium arvense)*, nutsedge (*Cirsium arvense)*, and dodder (*Cuscuta L.)* (USDA ARS, 2008, p 61). Most of these weeds, and others, are present throughout all the sugar beet growing regions. Weeds are classified as annual or perennial. An annual is a plant that completes its life cycle in one year or less and reproduces only by seed. Annuals are further classified as broadleaf or grass. Perennials are plants that live for more than two years. They may reproduce by seeds, rhizomes (underground creeping stems) or other underground parts.

Kochia (*Kochia scoparia)*, an annual broadleaf plant, is a member of the Goosefoot family, the same family as sugar beet. Weeds in the same family as a crop often thrive in the same growing conditions.

Pigweed (*Amaranthus spp.)* is a broadleaf annual that is a weed problem in many crops. There are several species; redroot pigweed is most common (UC Integrated Pest Management [IPM] 2010).

Common lambsquarter (*Chenopodium album*)is an annual broadleaf in the same family as sugar beets. With its rapid growth and large size it quickly removes soil moisture (McDonald et al, 2003).

Nightshade (*Solanum spp.)* is a broadleaf annual that grows 6-24 inches tall (McDonald et al, 2003).

Common mallow (*Malva neglecta)* and **cocklebur** *(Xanthium strumarium)* are widespread broadleaf annuals.

Barnyardgrass (*Enchinochloa crus-galli*, **foxtail** (*Setaria)*, **wild millet** (*Panicum miliaceum)* and **wild oats** (*Avena fatua)* are annual grasses.

Sowthistle (*Sonchus L.)* is a perennial plant that reaches a height of 3 to 7 feet and reproduces by seed and underground roots.

Canada thistle (*Cirsium arvense)* is a perennial that reproduces by seeds and underground roots and grows 2 to 5 feet tall. The roots extend several feet deep and some distance horizontally. Canada thistle is the most prevalent and persistent non-grass weed in Minnesota, and is the no. 1 noxious weed in Colorado. It is a problem weed in all growing regions. (Durgan, 1998, p. 8; Colorado Department of Agriculture, undated; McDonald et al, 2003, p. 10).

Nutsedges (*Cyperus spp.)* are among the most problematic weeds of agriculture in temperate to tropical zones worldwide. They are difficult to control, often form dense colonies, and can greatly reduce crop yields. Nutsedges reproduce primarily by rhizomes (UC IPM 2010).

Dodder (*Cuscuta L.)* is an annual parasitic weed that grows only by penetrating tissues of host plants to obtain water and nutrients. Each plant produces thousands of seeds that can remain dormant in the soil for years (UC IPM, 2010).

Velvetleaf (*Abutilon theophrasti*) is a broadleaf annual that grows 2-7 feet tall (McDonald et al, p. 12; USDA 1999a, pp. 18-19).

Ragweed (*Ambrosia spp.*) are annual broadleaf weeds that can be very competitive with crops.

2.5.4 Other non-herbicide weed management practices

In addition to crop rotation and tillage, discussed above, sugar beet growers of conventional sugar beets have other non-herbicide means to manage weeds. Narrow row widths (22 – 24 inches) are commonly used by both conventional and sugar beet growers and those growing glyphosate-tolerant sugar beets, for quicker canopy closure (Cattanach et al, 1991; McDonald et al, 2003; Mikkelson and Petrof, 1999, p. 21). With respect to glyphosate-tolerant sugar beets in particular, because these crops do not require cultivation (i.e., in-crop tillage), sugar beet growers are switching to narrow-row production. With narrower rows, glyphoste-tolerant sugar beets can achieve canopy closure earlier in the growing season, which deprives weeds of sunlight and therefore retards late season weed growth (Wilson, 2010b, p. 4). Growers also use weed-free seed. Additionally, nearly all growers scout their fields for weeds (Ali, 2004).

2.5.5 Use of herbicides to control weeds

Herbicide use is regulated by EPA under FIFRA, rather than by APHIS, and EPA has granted glyphosate reduced risk status (Schneider, 2008, p. 4). Herbicides are used by virtually all sugar beet growers; in 2000 approximately 98 percent of planted acres received one or more herbicide applications (Ali, 2004, Table 4). Herbicides may be used before the crop emerges from the ground (pre-emergence) or after (post-emergence). Pre-plant incorporated (PPI) herbicides are mixed in with the soil before planting. The application method, whether PPI, pre-emergence or post-emergence, largely determines when the herbicide will contact plants and the portion of the plant contacted. In selecting a herbicide, a grower must consider, among other factors, the potential adverse effects on the crop, whether the herbicide is registered for use on the crop, residual effects that may limit crops that can be grown in rotation, effectiveness on expected weeds, and cost.

Herbicide mode of action. Herbicides are chemicals that move into a plant and disrupt a vital process. They are classified according to their mode of action, which is the overall manner in which the herbicide affects a plant at the tissue or cellular level. Most herbicides bind to, and thereby block the action of, a specific enzyme.[26]

2.5.6 Weed control with conventional sugar beets

Conventional sugar beet growers use the weed control measures discussed above, plus a variety of herbicides. There are hundreds of commercial herbicides; only a fraction of that total can be appropriate for use with conventional sugar beet (Table 2-3).

[26] An enzyme is a biological catalyst and is usually a protein. Enzymes are discussed in more detail in Section 3.1.1.

The Weed Science Society of America (WSSA) has classified herbicides by group number, based on their mode of action. As shown in Table 2-3, herbicides commonly used with sugar beet include group numbers 1, 2, 3, 4, 5, 8, and 9 (Tranel, 2008, Dexter et al, 1994; Ross and Childs, undated):

Group 1 herbicides inhibit the action of the enzyme ACCase

Group 2 herbicides inhibit the action of the enzyme ALS

Group 3 herbicides inhibit cell division (mitosis inhibitors)

Group 4 herbicides mimic the plant growth hormone auxin and cause uncontrolled cell growth (synthetic auxins)

Group 5 herbicides inhibit photosynthesis

Group 8 herbicides inhibit a single key enzyme involved in fatty acid synthesis

Group 9 herbicides inhibit the action of the enzyme ESPSP

Table 2-4 summarizes the effectiveness of the herbicides in Table 2-3 on the important sugar beet weeds identified by USDA ARS. As the table shows, no single herbicide is effective on all weeds. Some of these herbicides can be mixed together and applied at the same time (tank-mixed). For conventional sugar beets, glyphosate can be applied only pre-emergence. Blank cells indicate no data were available for that source.

Current practices for weed control in conventional sugar beets include tillage, pre-plant incorporation of grass and broadleaf herbicides, and in-crop use of grass and broadleaf herbicide tank mixtures (Dexter and Luecke, 2003; Dexter and Zollinger, 2003; WSSA, 1994). Each of these practices has limitations. Cultivation and pre-plant incorporation of herbicides are associated with narrow windows of application, which is based on a specific weed size or crop stage (Baker et al., 1982; Baker and Johnson, 1979; Campbell and Janzen, 1995; Fawcett, 1995). Additionally, herbicide performance and crop injury are influenced heavily by soil pH, target weed size, crop size, air temperature, and irrigation practices. Morever, many of the currently applied herbicides leave soil residues, whose persistence can impact crop rotation options in subsequent seasons (Dexter and Zollinger, 2003; WSSA, 1994)

Table 2-3. Herbicide applications to sugar beet acres in the US, 2000[1]

Agricultural Chemical (Herbicide)	Trade Name (typical)	WSSA Mode of Action Group No.	Acreage Treated (%)	Number of Applications per Year	Rate per Application (lb/appli./ac)	Rate per Acre (lb/ac)	Total Applied per Year (1,000 lb)
Clethodim	Select	1	46	2.5	0.04	0.11	77
Clopyralid	Stinger	4	74	2.8	0.03	0.09	102
Cycloate	Ro-Neet	8	5	1.0	1.84	1.84	139
Desmedipham	Betanex	5	94	2.8	0.07	0.18	270
EPTC	Eptam	8	6	1.0	2.61	2.64	230
Ethofumesate	Nortron	8	37	2.1	0.06	0.14	82
Glyphosate	(Several)	9	13	1.1	0.39	0.43	86
Phenmedipham	Betamix	5	80	2.6	0.05	0.14	170
Pyrazon	Pyramin	HRAC Group C1	6	1.0	0.82	0.85	76
Quizalofop, ethyl	Assure II	1	10	1.6	0.04	0.06	9
Sethoxydim	Poast	1	11	1.7	0.19	0.33	56
Trifluralin	Treflan HFP	3	5	1.0	0.65	0.66	55
Triflusulfuronmethyl	Upbeet	2	83	2.7	0.008	0.02	29

[1] 1.565 million acres were planted in the US in 2000. All values are averages. Source: National Agriculture Statistics Service (www.usda.gov/nass); www.weedscience.org; www.hracglobalcom.

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Table 2-4. Effectiveness of herbicides on major weeds in sugar beets.

Herbicide	Broadleaves						Grasses				Perennials			Parasite
	Kochia	Pigweed	Nightshade	Cocklebur	Common lambsquarter	Common mallow	Wild oats	Barnyardgrass	Wild millet	Foxtail	Sowthistle	Nutsedge	Canada thistle	Dodder
Pre-plant incorporated														
Ro-Neet														
MI Sugar	P	G	F	P	F			G		G	N	G	N	
NDSU	P	F-G	F-G	P	F-G	F-G	F-G	G		G-E			N	
U of ID	P	E	G	P	E	P	F	G		G	P	F	P	P
Pre-emergence														
Nortron														
MI Sugar	F	G	G	F	G			P		F	N	P	N	
NDSU	F-G	G-E	F-G	P	P-F	P	F-G	P		F-G			N	
U of ID	F-G	G-E	F-G	P	G-E	P	F	G		G	G	P	P	P
Pyramin														
MI Sugar	P	G	G	P	E			P		P	N	N	N	
U of ID	P	G-E	F-G	P	G	P	P	P		P	P	P	P	P
Eptam														
NDSU	F	F-G	F-G	P	F-G	F-G	G	G-E		G-E			N	
U of ID	F	F-G	F-P	P	G	P	F-G	G		G	F	F	P	P

E= excellent, G = good, F = fair, P = poor, N = no effect.

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Table 2-4. Effectiveness of herbicides on major weeds in sugar beets.

Herbicide	Broadleaves						Grasses				Perennials			Parasite
	Kochia	Pigweed	Nightshade	Cocklebur	Common lambsquarter	Common mallow	Wild oats	Barnyardgrass	Wild millet	Foxtail	Sowthistle	Nutsedge	Canada thistle	Dodder
Post-emergence														
Nortron														
MI Sugar	-	F	G	P	F			P		F	N	N	N	
Pyramin														
MI Sugar	-	F	F	P	F			N		N	P	N	P	
Betamix														
MI Sugar	F	G	F	F	E			P		F	N	N	N	
NDSU	F	G	F-G	P-F	G	P	N	P		F			N	
U of ID	P-F	G-E	F-G	F	E	P	P	P-F		F	E	P	P	P
Betanex														
NDSU	P-F	G-E	F-G	P	G	P	N	P		P			N	
Upbeet														
MI Sugar	-	F	F	F	P			P		P	N	N	P	
NDSU	P-E	F	F	N	P	G	N	N		F-G			N	
U of ID	G	G-E	G	F	G	F	P	P		P	G	P	P	P

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Table 2-4. Effectiveness of herbicides on major weeds in sugar beets.

Herbicide	Broadleaves						Grasses				Perennials			Parasite
	Kochia	Pigweed	Nightshade	Cocklebur	Common lambsquarter	Common mallow	Wild oats	Barnyardgrass	Wild millet	Foxtail	Sowthistle	Nutsedge	Canada thistle	Dodder
Stinger														
MI Sugar	N	P	F	E	P			N		N	G	N	G	
NDSU	N	P	F-G	E	P-F	P	N	P		P			G-E	
U of ID	P	P	F-G	E	F	P	P	P		P	G	P	E	P
Progress (a mixture of Betamix plus Nortron)														
MI Sugar	F	G	G	F	E			P		F	N	N	N	
NDSU	F-G	G	G	F	G-E	P	N	P		F-G			N	
Assure II/Select (Assure II only for U of ID)														
MI Sugar	N	N	N	N	N			G		E	N	N	N	
NDSU	N	N	N	N	N	N	E	E		E			N	
U of ID	P	P	P	P	P	P	G-E	E		E	P	P	P	P
Poast														
MI Sugar	N	N	N	N	N			E		E	N	N	N	
U of ID	P	P	P	P	P	P	G-E	E		E	P	P	-	P

E= excellent, G = good, F = fair, P = poor, N = no effect.

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Table 2-4. Effectiveness of herbicides on major weeds in sugar beets.

Herbicide	Broadleaves						Grasses				Perennials			Parasite
	Kochia	Pigweed	Nightshade	Cocklebur	Common lambsquarter	Common mallow	Wild oats	Barnyardgrass	Wild millet	Foxtail	Sowthistle	Nutsedge	Canada thistle	Dodder
Glyphosate														
MI Sugar	G	E	G	E	G			E		E	-	F	G	
NDSU	F-E	E	P-G	E	P-E	P-G	G-E	E		E			G-E	
Select														
U of ID	P	P	P	P	P	P	G-E	E		E	P	P	P	P
Treflan HFP														
U of ID	F	G	P	P	F-G	P	F	G		G	P	P	P	P

E= excellent, G = good, F = fair, P = poor, N = no effect.

Blank cells mean no data were available for that source.
Sources: MI Sugar: Michigan Sugar, 2009; NDSU: Stachler and Zollinger, 2009; U of ID: Morishita, 2009

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Conventional weed control options are complex due to the need for several applications of multiple tank-mixed herbicides to achieve long-term, broad-spectrum weed control. As an example, a common practice in sugar beet production is to use "micro-rates" of herbicides (Dexter and Zollinger, 2003). This is accomplished by tank mixing multiple herbicides at reduced rates in combination with an oil additive. The components of the tank mixture may include Betanex (desmedipham), Betamix (phenmedipham + desmedipham), Nortron (ethofumesate), Upbeet (triflusulfuron methyl), and Stinger (clopyralid); and Select (chlethodim), if grasses are present. A minimum of three applications is recommended, beginning at the cotyledon growth stage and followed by weekly applications of this herbicide mixture. The intent of the micro-rate program is to lower overall herbicide costs and reduce the potential for crop injury.

A member of the Minn-Dak Farmers Cooperative, who farms about 1,100 acres of sugar beets annually, described his conventional weed control system (Mauch, 2010, pp. 2-3):

> Prior to planting Roundup Ready® sugar beet, my herbicide regimen for conventional beet seed was very complicated and labor intensive. Pre-emergence, I used a combination of Eptam (which is very toxic to the sugar beet) and RoNeet (which is very expensive). Approximately two weeks after the beet plants emerge, I started spraying a mix of BetaMix, Betanex, UpBeet, Nortron and Stinger and adjunctives to make the herbicides stick better to the crops. This would be sprayed four times (approximately once a week). Even after spraying several times, there were still weeds and I then needed to hire manual labor to hoe and pull out the weeds.

This description of the complexity of conventional weed control is similar to that provided by researchers evaluating weed management in sugar beets (Odero et al, 2008). Odero et al evaluated 20 different weed treatment alternatives for conventional sugar beets and found that the following treatment yielded the highest net economic return: PPI treatment with Nortron (ethofumesate), followed by three micro-rate treatments of a tank mixture of Betamix (phenmedipham + desmedipham) and Nortron (ethofumesate), followed by Outlook (dimethenamid-P); with hand-hoeing following each herbicide application.

Other researchers have also found that a combination of herbicides plus hand hoeing is required to effectively control weeds in conventional sugar beets (Dexter and Luecke, 2003).

Hand-weeding is necessary in many situations; however, it is cost-prohibitive as a replacement for herbicides. USDA data shows that in 2000, conventional sugar beet growers spent an

average of $94.28/acre for all chemicals (insecticides, herbicides, fungicides, etc.) (Ali, 2004, p. 7). Five-year studies of the cost of hand-weeding sugar beet at the University of California – Davis, as reported by the California Beet Growers Association, found that the cost of hand weeding was between $260 to over $650 per acre (California Beet Growers Association, 1999, p. 29). Using the midyear of 1996 as the base year, this is equivalent to approximately $373 to $914 per acre in 2010 dollars, or approximately three to seven times what sugar beet growers spent on all chemicals. More recently, scientists in Wyoming have found that net returns for optimal herbicide application combined with hand weeding are more than twice the net returns for hand weeding alone (Odero et al, 2008, Table 4).

2.5.7 Weed control with event H7-1

In-crop applications of glyphosate can be made from crop emergence up to 30 days prior to harvest. This flexibility allows the grower a wider window of application, with the application timing based on weed pressure, not on crop stage. Typically only 2-3 post-emergence applications of glyphosate are applied with GE sugar beets (Mauch, 2010; Grant, 2010). The broad spectrum of weed control offered by glyphosate (Table 2-4) reduces the need for tank mixing with additional herbicides. However, the use of other herbicides in combination with or in sequence with glyphosate is recommended as needed under specific conditions to address select weed and/or weed resistance issues.

Monsanto's Technology Use Guide (TUG, 2010, Appendix E) provides specific weed control recommendations for event H7-1 sugar beet. The TUG recommends the use of "mechanical weed control/cultivation and/or residual herbicides" with event H7-1 sugar beets, where appropriate, and "additional herbicide modes of action/residual herbicides and/or mechanical weed control in other Roundup Ready® crops" rotated with event H7-1 (TUG, 2010, p. 40).

2.6 HERBICIDE RESISTANCE

Herbicide resistance is "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type" (WSSA, 1998).

Herbicide resistance is a result of natural selection. Plants of a given species are not all identical; they are made up of "biotypes" with various genetic traits. Biotypes possess certain traits or characteristics not common to the entire population. Herbicides, that suppress or kill weeds, can exert selection pressure on weed populations. When a herbicide is applied, the plants with resistance to it, which had no special survival qualities before the herbicide was

introduced, become the survivors who are then able to reproduce and pass on their genes. With repeated application of the same herbicide and no other herbicide or weed control practice, the resistant biotype becomes the dominant biotype in that weed community. In the mid-1950s, Harper (1957) theorized that annual, repeated use of any herbicide could lead to shifts in weed species composition within a crop-weed community. Similarly, Bandeen et al. (1982) suggested that a normal variability in response to herbicides exists among plant species and tolerance can increase with repeated use of an herbicide. Indeed, as of June 27, 2010, 341 herbicide resistant weed biotypes have been reported to be resistant to 19 different herbicide modes of action (Heap, 2010). Glyphosate-resistant weeds account for 5 percent of the herbicide resistant biotypes while weeds resistant to herbicides that inhibit acetolactate synthase (ALS), such as Upbeet, account for 31 percent of the herbicide resistant biotypes. (Wilson, 2010a, p. 6).

Figure 2-3 shows the increase in herbicide resistant biotypes with time. Among the herbicides commonly used in conventional sugar beet, Assure II, Poast, and Select are ACCase inhibitors; Upbeet is an ALS inhibitor; Treflan HFP is a dinitroaniline; Stinger is a synthetic auxin, and glyphosate is a glycine. Figure 2-3 shows only the number of confirmed resistant biotypes. The total extent and distribution of resistant biotype varies widely. Details of herbicide resistant weed in sugar beets are discussed in Section 3.12.

For as long as herbicide resistance has been a known phenomenon, public sector weed scientist, private sector weed scientist and growers have been identifying methods to address the problem. For instance, when a farmer uses multiple weed control tools to achieve weed control, herbicide resistance biotypes will be controlled and the resistance biotype generally will not become the dominant biotype within a population (Gunsolus, 2002; Cole, 2010a, p. 4). By contrast, weed resistance is known to occur most rapidly in areas where there is a sole reliance on a single herbicide used repeatedly over multiple crop generations for the management of a specific weed spectrum.

When a grower encounters a biotype that is resistant to an herbicide he is using, the grower must use an alternate method of weed control. Management practices that can be used to retard the development of resistance, such as those routinely used by sugar beet growers, include herbicide mixtures, herbicide rotation, crop rotation, and increased cultivation.

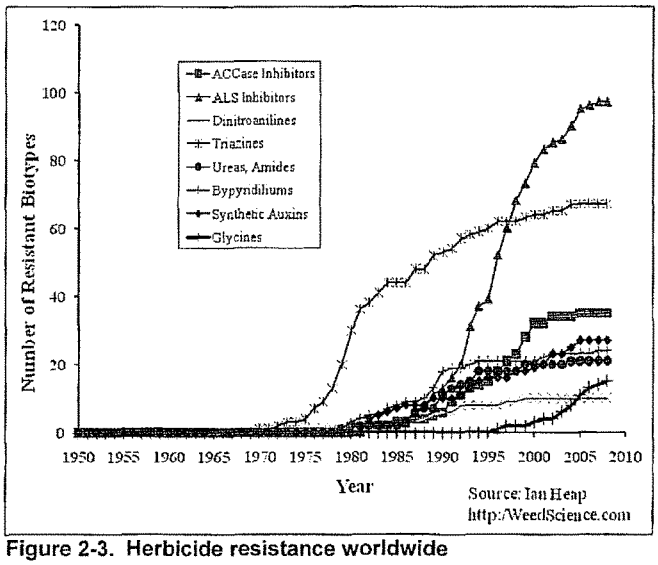


Figure 2-3. Herbicide resistance worldwide

Management practices that can be used to retard the development of resistance, such as those routinely used by sugar beet growers, include herbicide mixtures, herbicide rotation, crop rotation, and cultivation. The WSSA reports: "Weed scientists know that the best defense against weed resistance is to proactively use a combination of agronomic practices, including the judicious use of herbicides with alternative modes of action either concurrently or sequentially" (WSSA, 2010b).

2.7 SUGAR BEET SEED PRODUCTION

2.7.1 Variety development

When developing plant varieties for commercial release, plant breeders select individual plants with desirable characteristics, such as higher yields or pathogen resistance. This breeding involves transferring pollen from one source plant to fertilize another plant. Once plants with the desired traits have been selected, a population of those plants with similar characteristics are classified as varieties.

Commercial sugar beet variety development has been done exclusively by private sugar and seed companies in the US. Currently these are Crystal/ACH, Hilleshog (Syngenta), Seedex,

Betaseed (KWS) and SESVanderhave/Holly. As plant breeders continue to develop new germplasm, the identification of desirable traits (e.g., resistance to specific diseases, high sugar content, etc.) is incorporated into the development of new varieties. Due to geographic variability in weather, growing conditions, climate, insect and disease susceptibility vary from region to region, different varieties are developed for different regions. Sugar beet company selection committees in each region establish a list of approved varieties based on coded variety trials, which are designed to give an unbiased evaluation of the genetic potential of all sugar beet variety entries while other variables (stand, fertility, moisture levels, etc.) are kept constant. Growers may grow only those varieties that appear on the sugar beet company approved list for that region. Variety trials insure the use of the most productive varieties to maximize returns to the growers and sugar companies. Trials last 2 to 3 years and involve millions of plants each year.

2.7.2 Hybrids and cytoplasmic male sterility

To produce seed for commercial planting of the chosen variety, some crops, such as cotton and soybeans, rely on the same individual plant to serve as the female (pollen acceptor) and male (pollen donor) to produce seed. Other crops, such as corn and sugar beet, rely on two different varieties, called inbreds, to produce hybrid seed that carries traits from both parent lines. Hybrid varieties typically exhibit greater vigor than the parent lines on which they are based, resulting in plants with higher yields, better resistance to stress, and other desirable traits.

Once a biotech plant such as event H7-1 has been developed, researchers will use that plant to breed the biotech trait to other varieties. In breeding sugar beet varieties for future commercial production, the biotech trait could be maintained on either the male or female plants. For greater breeding flexibility and efficiency in producing new varieties, plant breeders may prefer to breed additional varieties by introducing the biotech trait on male pollinator population of plants and use those plants to fertilize the same male-sterile female plants (Skaracis and De Biaggi, 2005). If the biotech trait is only on the female (male sterile) plant with CMS, as discussed below, that trait cannot be transferred to other plants in order to breed new inbreds. In hybrid sugar beet seed production, although each plant flower contains both male (the anther) and female (the stigma) parts, individual plants can be made female-only, or male sterile. Male sterility results in the failure of plants to produce functional anther, pollen or male gametes (Hovland, 2010, p. 2). In order for seed multiplication of the male sterile or female plant to occur, plant breeders develop a partner line ("O-Type") which is genetically identical to its equivalent male sterile or female line with the exception of its ability to produce pollen. This

identical O-Type is then used as the pollinator (male plant) to pollinate the female plant, resulting in offspring that will again be male sterile and not produce pollen. This seed, after meeting quality criteria relative to any impurities, is then used as the male sterile or female basic seed in the commercial seed production fields. This system is known as Cytoplasmic Male Sterility (CMS). It is the system used in many other crops to develop male sterile or female basic seed lines that do not produce pollen. Using female-only plants in seed production ensures that the hybrid seed harvested from those plants will be a cross between the two parent lines. Male and female lines are planted in alternating strips in a sugar beet seed production field, typically with two to four times as many female rows as male rows to maximize the amount of seed collected (Hoffman, 2010a, p.5). Often stecklings (small transplants) are used for the male lines. After pollination occurs, the male plants are destroyed (Holly Hybrids, 2007). Only very rarely would a CMS fertile plant produce pollen and such plants can be identified and rogued.

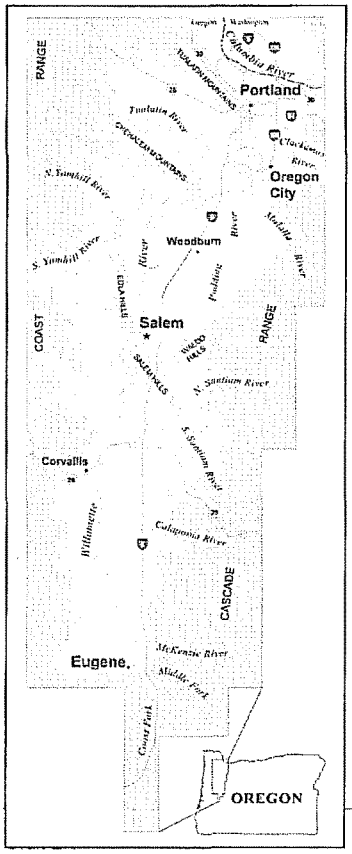


Figure 2-4. Willamette Valley
Source: Givler and Wells, 2001

One producer reports identifying only two pollen-producing plants within a crop of over eleven million total plants (Anfinrud deposition, 2010, 178).

In the Willamette Valley, 78.6% of the 2009-2010 seed crop were grown with the glyphosate-tolerant trait on the female inbred. These female inbreds are male sterile because of the CMS trait and thus are bred not to produce pollen. (Preliminary Injunction Hearing, March 5, 2010, pgs. 17-18; 25). Therefore, the risk of transferring the glyphosate-tolerant trait to other plants from these seed production fields is negligible or zero.

2.7.3 Commercial sugar beet seed production

Willamette Valley

At least ninety-five percent of the Oregon sugar beet seed production (equal to 70% or more of the total US

production), is in the Willamette Valley, located between the Coast Range and the Cascade Range (Figure 2-4 at left) (Stankiewicz Gabel, 2010, p. 7). The valley is over 100 miles long. The climate is cool enough for winter vernalization (prolonged exposure to a minimum cool temperature for a prolonged period of time that enables the plant to flower) but warm enough for the roots to live through the winter. Summers are very dry, producing ideal conditions for seed harvesting. While sugar beet is normally a biennial plant, conditions in the valley are such that seed can be produced in one year rather than two. Sugar beet seeds are planted in August or September and vernalize over the winter. The following spring, the plant produces a seed stalk (bolt). Seeds are harvested in late July to August. One seed company, Betaseed, grows the basic and commercial seed for its varieties at the southern and southeastern fringes of the Willamette Valley.. Syngenta develops its varieties elsewhere, and then ships the basic seed to West Coast Beet Seed Company (WCBS) for the commercial production. SESVanderHave develops its varieties both in the Willamette Valley and elsewhere, and ships basic seed produced elsewhere to West Coast Beet Seed Company (WCBS) for seed production. WCBS is jointly owned by a group of sugar beet seed and sugar companies.

With its unique growing conditions, the Willamette Valley is used for seed production for many different kinds of seeds. In addition to seeds, many vegetables are also grown in the valley. It is a major area for production of "most temperate vegetables, herbs and vegetable seeds" (Mansour, 1999). Because high quality and seed purity are important to many growers, and because the valley is the site of varied seed production, sugar beet seed production companies have worked cooperatively to develop and implement protocols to maintain seed purity and quality. Most seed companies, including both WCBS and Betaseed, belong to the Willamette Valley Specialty Seed Association (WVSSA) and follow the guidelines for isolation and minimum separation distances between fields (Appendix A).

WCBS and Betaseed have developed explicit standard operating procedures and grower guidelines that are intended to minimize and/or eliminate the possibility of inadvertent seed mixing (Appendix B).

Maintaining the integrity of seeds

Currently, the WVSSA implements pinning procedures and isolation guidelines for seed production within the Willamette Valley. Pinning procedures identify the geographic location of production fields by placing pins and flags on a map. This is used to establish isolation distances between seed production fields. Additionally, WCBS and Betaseed have instituted

protocols and management practices to further maintain the integrity of seed which are essentially the same as required by Item 4 of the interim measures (Section 1.1.3). Seed production and quality control are a significant cost, to seed companies, and these companies within the Willamette Valley and throughout seed production areas carefully control growing conditions and production practices to ensure that seed is pure and of high quality – despite the fact that quality control in seed production carries significant cost.

WCBS Seed Production. WCBS currently produces much of the sugar beet seed for some of the sugar beet seed companies.. WCBS obtains basic seed from these sugar beet companies to further increase these small seed volumes into larger commercial quantities. Management of these fields and planting locations is controlled utilizing a tracking and tracing system distinguishing seed lots from the moment of initial delivery of seed, designated for seed production, to WCBS throughout the subsequent planting and harvest. This management further continues until the delivery of the finished packaged seed to the customer. Some companies further incorporate various computerized and digital tracking systems designed to manage real-time seed batch movement and quality testing. Many of these companies have sealed packaging and specified color coding designations to further identify seed batches/lots. (Meier, 2010, p. 3). Similarly, other companies ship event H7-1 sugar beet seed in packages accompanied by a declarations document that states the event H7-1 status of the basic seed (Anfinrud, 2010, p. 2).

WCBS contracts to individual growers for seed production. WCBS prohibits production of a red beet or Swiss chard seed crop by any WCBS grower in a year in which that grower is producing sugar beet seed, whether genetically engineered (GE) or conventional. WCBS also prohibits the sharing of planting, cultivation and harvesting equipment for red beet/Swiss chard and sugar beet seed, whether they are producing GE or conventional sugar beet seed (Loberg, 2010, p. 2; also in Appendix B of this ER[27]). In addition, WCBS requires its growers, by contract, to adhere to minimum isolation distance within a three mile radius of any GT field (Appendix B).

WCBS maintains control of all material, whether GE or conventional, from point of origin to return of the seed to the seed company (Appendix B). This includes control of the disposal of any excess GE stecklings that are not used for seed production. When those stecklings are not used for seed production and remain in the nursery field, such stecklings are uprooted and

[27] These requirements are in the Appendix B WCBS protocol, under the heading "GM Grower Guidelines." While the title is "guidelines," the protocol is clear that these restrictions are included in WCBS contracts with growers.

mixed into the soil during tillage for soil preparation for the next crop. Destruction occurs with this tillage and is followed by chemical control in the subsequent crop. Stecklings that are removed from the nursery, but are not used, are destroyed or securely disposed. The prevailing method is returning unused stecklings to the nursery field of origin and subsequent destruction through standard agricultural practices (physical destruction with tillage and chemical destruction in the subsequent crop) (Loberg, 2010, p 2; and Appendix B of this ER).

Precleaning of seed at WCBS for shipment to the seed development company takes place in the dedicated WCBS facility. This process removes sticks, chaff, weeds and the like that may be contained in the seed when initially harvested. Because WCBS does not handle red beet or Swiss chard seed, its seed precleaning operations present no opportunity for mechanical mixing of sugar beet seed, whether conventional or GE, with red beet or Swiss chard seed. In years when WCBS produces both GE and conventional sugar beet seed, physical separation requirements and cleaning protocols protect against inadvertent mixing. In 2009, only two growers produced conventional seed for WCBS. All of this conventional seed was pre-cleaned at the end of the season, after completion of the pre-cleaning of the event H7-1 seed and after complete cleaning of the equipment.

After the pre-cleaning, WCBS returns the seeds to the seed development company in sealed containers with color-coded labeling and shipping documents, which are checked upon arrival at seed processing facilities. Syngenta, for example, marks each container with a computer-generated and tracked batch number (Meier, 2010). SESVanderHave labels its event H7-1 seed with an orange triangle. (Anfinrud, 2010, at p. 3).

Betaseed seed production. Betaseed performs its own basic seed production, and like WCBS, it contracts commercial seed production to individual growers. Betaseed has adopted standard operating procedures (SOPs) that require all materials to be adequately identified and tracked through a computerized, bar-coded system from basic seed production to commercial seed production to final processing and shipping. All Betaseed personnel involved in seed production are trained in the SOPs and required to sign an acknowledgement that they have read, understood, and will comply with the SOPs (Lehner, 2010, p. 10).

Betaseed supervises its commercial seed growers' practices for conformance with Betaseed's stewardship requirements. Betaseed's grower contracts provide for such supervision, as well as Betaseed's right to enter the grower's fields and take remedial action if the grower does not

comply with Betaseed's instructions. Betaseed pins all of its commercial seed fields in compliance with the WVSSA's pinning rules to ensure that isolation distance guidelines are followed. In addition, Betaseed requires its growers, by contract, to adhere to isolation distances of four miles from other crops that may cross-pollinate with sugar beets.. Betaseed also requires growers to clean their equipment before and after harvesting a sugar beet variety, and to monitor for and eliminate volunteer sugar beets. According to the SOPs, Betaseed personnel are present for the beginning of every harvest by a commercial grower. Betaseed provides bar-coded tote boxes into which the harvested seed is placed for transport to Betaseed's processing facility (Lehner, 2010, pp. 3-5).

Betaseed performs "grow-outs" each year in which it plants samples of its commercial seed lots to ensure that the seed produces the expected variety of plant. Betaseed's grow-out observation plot did not produce any off-types this year (Lehner, 2010, p. 3).

Syngenta seed processing. Syngenta processes sugar beet seed in its facility in Longmont, Colorado that is used only for sugar beet processing; a small percentage of the seed is processed by third party seed vendors in separate facilities dedicated to sugar beet processing (facilities where no red beets or Swiss chard seeds are processed). Processing of seed requires seven months and involves polishing, sorting by size, pelleting, treatment with fungicides and insecticides required by certain customers, coloring, packaging and shipping to growers in sealed packages. Syngenta maintains an extensive tracking and tracing system for every seed lot. This system includes a visual color identification of all RRSB material; a computerized, real-time record of seed batch movement, periodic germination and genetic identity testing; and extensive employee training. Syngenta also uses cleaning protocols to prevent any inadvertent mixing of RRSB and conventional sugar beet seed during processing. The cleaning process requires the removal of all RRSB seeds from the equipment and the plant floor. "Chase" seed is used to ensure that all GT seed has been removed from the equipment (Meier, 2010). with color-coded labels (Meier, 2010).

SESVanderHave seed processing, storage, treating, packaging, warehousing, transportation and distribution. Neither SESVanderHave, its growers nor its contractors are involved in any respect in chard or red beet breeding, production or processing. SESVanderHave's GE protocols require that conventional seed and event H7-1 seed are never handled or processed at the same time. For example, SESVanderHave does not allow its

processing contractors to process conventional seed at the same time that they are processing event H7-1 seed. (Anfinrud, 2010, p. 3).

SESVanderHave receiving/storage of unprocessed seed protocols. SESVanderHave has additional GE protocols that apply to unprocessed seed shipped from West Coast Beet Seed. All event H7-1 seed products are identified upon arrival at bulk storage facilities. Shipping documents from West Coast Beet Seed are used to double check the seeds that arrive in Sheridan, Wyoming facilities. Also, proper disposal of reject or spilled seed is established by variety, lot and size. Product is unloaded only after insuring that storage bins and label bins have appropriate markings (event H7-1 products are labeled with an orange triangle). (Anfinrud, 2010, p. 3).

SESVanderHave seed processing/storage protocols. Seed processed on behalf of SESVanderHave by third parties are subject to contractual arrangements that require compliance by processing contractors with SESVanderHave's GE protocols designed to prevent mixing of event H7-1 seed with other seeds during the various processing, treating, packaging, warehousing, transportation and distribution stages. Before dumping seed into the seed processing line, necessary equipment (conveyors, legs, distributors, storage bins) is cleaned. Product is unloaded only after insuring that storage bins have appropriate markings (event H7-1 products are labeled with an orange triangle). A key lock and appropriate label is placed on each bin discharge slide. Once product is in storage bins, the tops of bins are sealed by tinning pipe. If necessary, unloading equipment is cleaned and seed is disposed of in proper manner followed by a documented inspection. Bins with event H7-1 products are labeled with an orange triangle. Processed seed is placed into properly labeled storage totes and clean-down procedures are followed between seed lots. Rejected seed is disposed in a local landfill. All event H7-1 seed totes are labeled with an orange triangle. Totes are then transferred to the warehouse and put in inventory by variety, lot number, warehouse and slot. (Anfinrud, 2010, p. 3).

SESVanderHave treating and packaging protocols. Product to be primed, pelleted, treated and packaged is identified. When event H7-1 seed enters any facility under contract with SESVanderHave, the necessary equipment (legs, distributors, blending system, Delta screen, treater, conveyors, aspirators, and bagging scale) is thoroughly cleaned before the product is introduced. All processes require documentation of weights introduced and weights after contract processing is complete. All contractors have been audited by SESVanderHave

personnel to assure compliance with GE protocols. Final packaging of event H7-1 seed is done in approved packages with proper labels. Packaged seed is transferred to the warehouse and put on inventory by variety, lot, treatment, warehouse, and slot. When treating of event H7-1 seed is completed, if necessary, all treating/packaging equipment is cleaned following clean-down procedures. Reject seed is disposed of in an appropriate manner. (Anfinrud, 2010, p. 4).

SESVanderHave warehousing, transportation and distribution protocols. Seed to be shipped is identified by printing delivery orders that identify event H7-1 seed. Warehouse crews stage loads. Each pallet of event H7-1 seed is identified with a cover sheet. Any broken bags during transportation are recovered and returned to the originator for proper repair or disposal. Drivers are informed that event H7-1 seed is present on loads. Sales and marketing personnel confirm that event H7-1 seed shipments are to approved customer locations (Anfinrud, 2010, p. 4).

SESVanderHave Auditing of Compliance with GE Protocols. SESVanderHave audits its contractors' compliance with its GE protocols as well as its own compliance to assure that SESVanderHave's standards of stewardship are maintained. SESVanderHave employees as well as outside consultants have worked on the audits, which have covered production, storage, processing, priming, pelleting, coating, packaging, handling, shipping and distribution of event H7-1 sugar beet seed. (Anfinrud, 2010, p. 4).

Betaseed seed processing. Betaseed processes and packages its own seed for distribution. Betaseed does not produce or process seed of any *Beta* species other than sugar beets, so there is no potential for mixing of GE seed with seed of any other *Beta* species in Betaseed's processing facility (Peters, 2010, p. 2).

Betaseed employs a computerized tracking system to ensure that all of its varieties of seed are kept separate as they are processed. All processing steps are recorded and auditable. Every box of seed that is processed is accompanied by both a human readable label and a bar-code containing information about the seed, including whether it is GE or conventional. Seed cannot be loaded into Betaseed's processing equipment until the bar-code accompanying the seed has been scanned and the seed is determined to be of the intended variety. In the last two seasons, Betaseed has only processed one variety of conventional seed (and only a single lot of this variety in the last season). To avoid the possibility of any mixing of GE seed with the conventional variety, Betaseed processed its conventional seed before processing any of its GE seed. Betaseed thoroughly cleans its entire processing system before and after processing conventional seed (Peters, 2010, pp. 2-4).

Betaseed also conducts bioassay tests on each lot of seed at least twice as the seed is processed through its plant to ensure that lots of GM varieties are glyphosate resistant and that conventional varieties do not contain GM seeds (Peters, 2010, p. 4).

2.8 RED TABLE BEET, SWISS CHARD, AND SPINACH BEET PRODUCTION

2.8.1 Vegetable beet production

In the USDA database, "beets" include red table beets, Swiss chard, and spinach beets (grown for the leaves). In the following discussion, these products are referred to as "vegetable beets." In 2007, the most recent year for which published data are available, 8,412 acres of beets were harvested in the US, on 2,744 farms, for an average of three acres per farm. Approximately 63 percent of the acreage was for processed beets, and the rest for the fresh market (USDA NASS, 2010b). The total value of vegetable beet production in 1999, the most recent year for which USDA has data available, was approximately $7 million. Based on the most recent year for which USDA has both harvested acreage and production value data (1997), the average value of vegetable beet production per acre was approximately $720, which would be roughly $1,000 in 2010, adjusted for inflation (USDA NASS, 2010b).

There is little overlap between areas of major vegetable beet production and sugar beet root production. Over half the 2007 acreage of vegetable beets (59 percent) was in two states, New York and Wisconsin, where sugar beets are not grown. California harvested 979 acres of vegetable beets in 2007. All California counties with five or more harvested acres reported are coastal. [28] Sugar beets are grown only Imperial County in California. Oregon harvested 425 acres of vegetable beets, but no vegetable beet production was reported in the two Oregon counties with sugar beet root crops; however, some vegetable beet crops are grown in the Willamette Valley. One county in Colorado (Larimer), and one county in Michigan (Lapeer), reported both sugar beet and vegetable beet harvests. No more than 7 acres of vegetable beets were harvested in any single Minnesota county. Harvested vegetable beet acreage for all other sugar beet producing states in 2007 was ten acres or less each (Montana, Idaho, Nebraska, North Dakota, and Wyoming) (USDA NASS, 2010b). Although there is little overlap in major production areas, based on USDA FSA (Farm Service Agency) data, vegetable beet crops and sugar beet crops can sometimes be found growing in adjacent fields (Stankiewicz Gabel, 2010, p. 8).

[28] These results, which don't distinguish between organic and conventional, are not completely consistent with the State of California organic results discussed in Section 2.4.3, probably because of variations in the database of growers reporting.

2.8.2 Red table beet and Swiss chard seed production

The most comprehensive data currently available for red table beet and Swiss chard seed production is from the FSA, however, the FSA does not distinguish between organic and conventional. Also, FSA does not include leaf beet seed production, which is apparently minor. According to data from the USDA FSA, red table beet seed in 2009 was grown on approximately 1,130 acres, with 92% grown in Washington State, 7% in Oregon and 1% in California; and Swiss chard seed in 2009 was grown on approximately 166 acres, with 51% grown in Washington State and 49% in California. Based on FSA data, there are no counties where both Swiss chard and table beet seed are grown, and only one county, in the Willamette Valley, where both sugar beet seed and table beet seed are grown. In that county the FSA data lists only two table beet seed fields. The total FSA-reported red table beet seed production in Oregon is approximately 79 acres (Stankiewicz Gabel, 2010, p. 7). There is also minor Swiss chard seed production in Oregon.

Based on older USDA published data, ninety-five percent of US red table beet seed production (650 to 700 acres) occurs within the small-seeded vegetable seed production area of western Washington State that includes Skagit, Island and Snohomish counties (See Figure 2-1 for locations) (Foss, 2007). These data do not exactly match the FSA data because they are for different years, and planting practices change from year to year.

Neither sugar beet root crops nor sugar beet seed crops are grown in the part of western Washington where the majority of the US red table beet and Swiss chard seed production occurs. Very little sugar beet root crop is produced in Washington State; the nearest processing facility is far to the south, in southern Idaho. In 2008, only one county, Benton reported sugar beet production (1,600 acres) (USDA NASS, 2010b). Benton County is in the Columbia Basin on the east side of the Cascade Range. There is no reported production of *Beta* seeds other than minor sugar beet in the Columbia Basin.

Due the extreme distance of this sugar beet production area from the Idaho processing facility, it is very unlikely that anyone would consider growing west of the Cascade range, in the area of other *Beta* production. As set forth in Section 2.3.2, transportation costs and proximity to a processing facility are key limiting factors in where to grow sugar beets.

The locations of red table beet and Swiss chard seed production in California are not known, but sugar beet root crops are grown only in the Imperial Valley, and these are conventional sugar beets.

As discussed in Section 2.7.3, the majority of the US sugar beet seed production occurs in the Willamette Valley where seed production for the various beet products (sugar beet, table beet and chard) is divided along geographical lines. Sugar beet seed is grown in the southern and central portions of the valley, table beet seed is grown in the northern region, and Swiss chard seed is grown at the margins.[29] The total estimated red table beet and Swiss chard seed production in the Willamette Valley in 2010 is 100 to 120 acres (McReynolds, 2010). Based on the FSA data, this appears to be all or virtually all of red table beet and Swiss chard seed production in Oregon.

Commercial seed production for red table beet is similar to that for sugar beet. Seed companies retain ownership of the seed, the growing crop, and the harvested seed. Growers produce and harvest the crop, and are then paid the contract price if the resulting seed meets contract quality criteria, typically an 85 percent seed germination rate and 99 percent purity (Foss, 2007).

Typically, the red table beet crop is planted in seed beds in mid-June. Plants not displaying true varietal characteristics are removed by hand. In October, the beets are topped mechanically, dug, placed in windrows, and covered with about one foot of soil to protect the roots against freezing during the winter. In March or early April, the over-wintered roots (stecklings), are removed from the windrows and brought to Skagit County for transplanting into production fields. Exposure of the roots to the winter season in windrows, followed by transplanting into fields in the spring, vernalizes the stecklings. Seed harvest occurs in late summer and early fall (August to September). The crop is cut, placed in windrows, dried 10 to 14 days in the field, and then threshed mechanically to capture the seed (Foss, 2007).

No information for Swiss chard seed production practices was found.

[29] Morton, 2010, p. 149:24-150:20.

2.8.3 Organic Red Table Beet and Swiss Chard Production

California is the only state for which organic red table beet and Swiss chard production data are publicly available. In USDA's reports, red table beets and Swiss chard are included in the "other vegetable" organic category. California accounts for 76 percent of "other" organic vegetable production within the sugar-beet producing states, and there is very little or no organic production of red table beets, Swiss chard, or leaf beets in the four major sugar beet production states (MN, ND, MI and ID) (Figure 2-5) (USDA, 2010c). The 2007 acreage and dollar value of organic red table beets and Swiss chard in California are shown in Figures 2-6 through 2-9. No data were found for organic seed production of red table beets, Swiss chard or spinach beets.

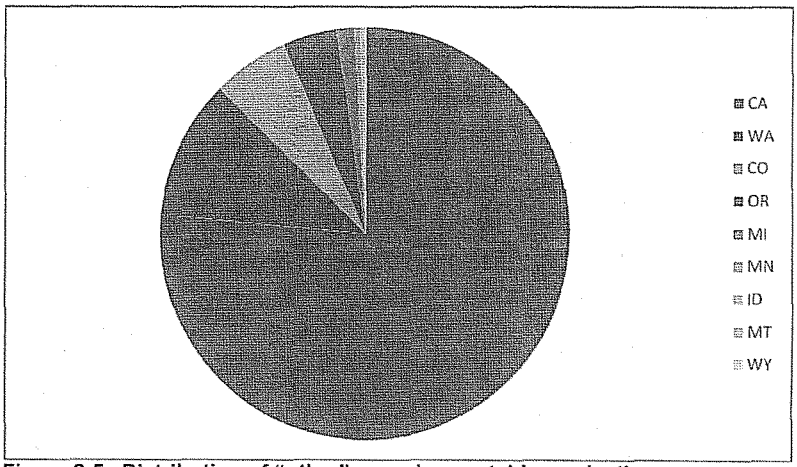


Figure 2-5. Distribution of "other" organic vegetable production across sugar beet producing states, 2008

Source: USDA, 2010c

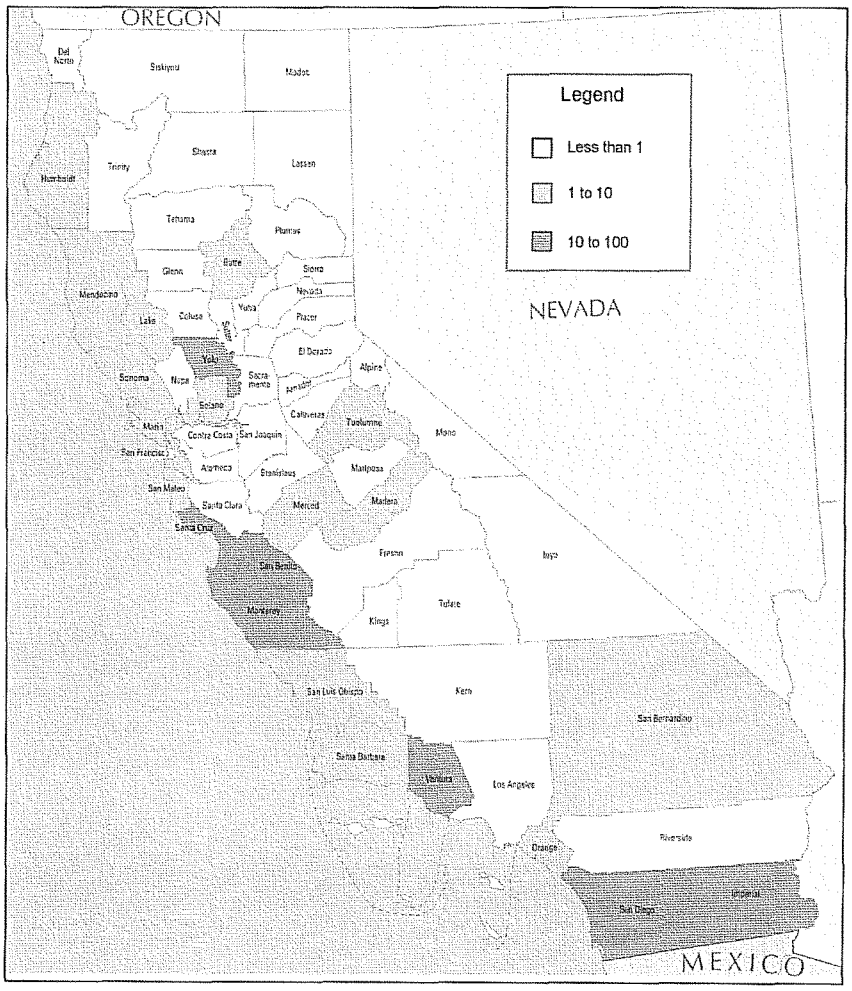


Figure 2-6. California acreage of organic beets (non-sugar), 2007

Source: California Department of Food and Agriculture, 2010

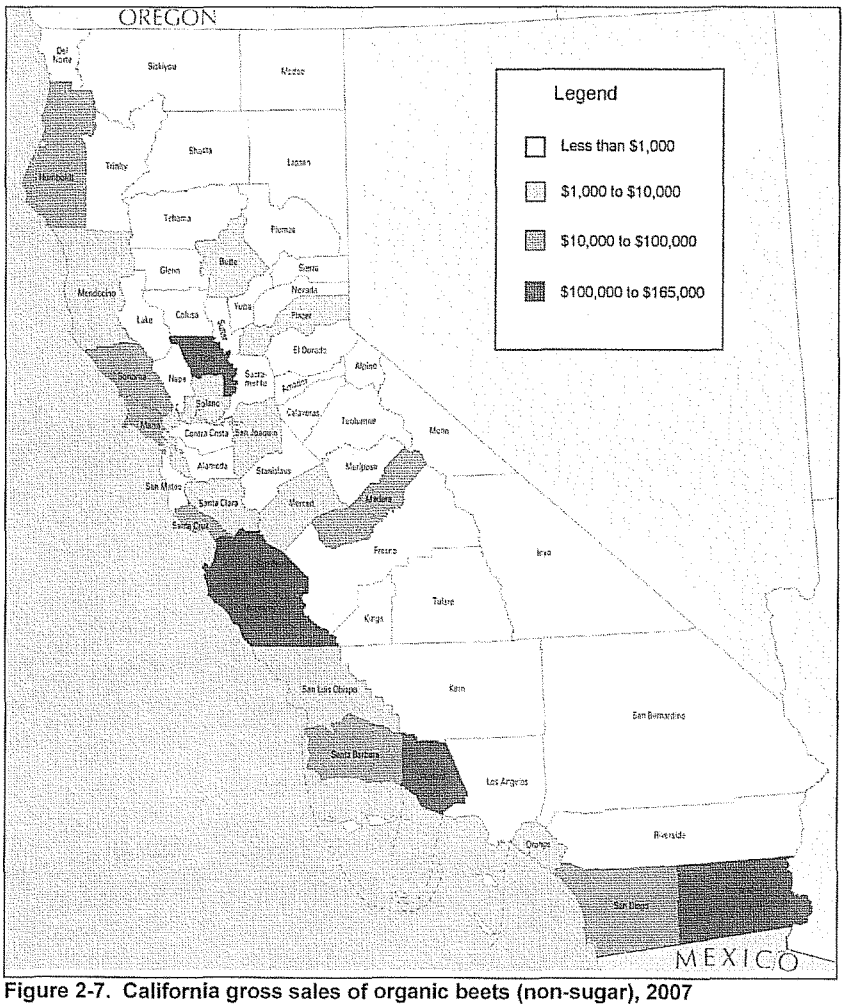


Figure 2-7. California gross sales of organic beets (non-sugar), 2007

Source: California Department of Food and Agriculture, 2010

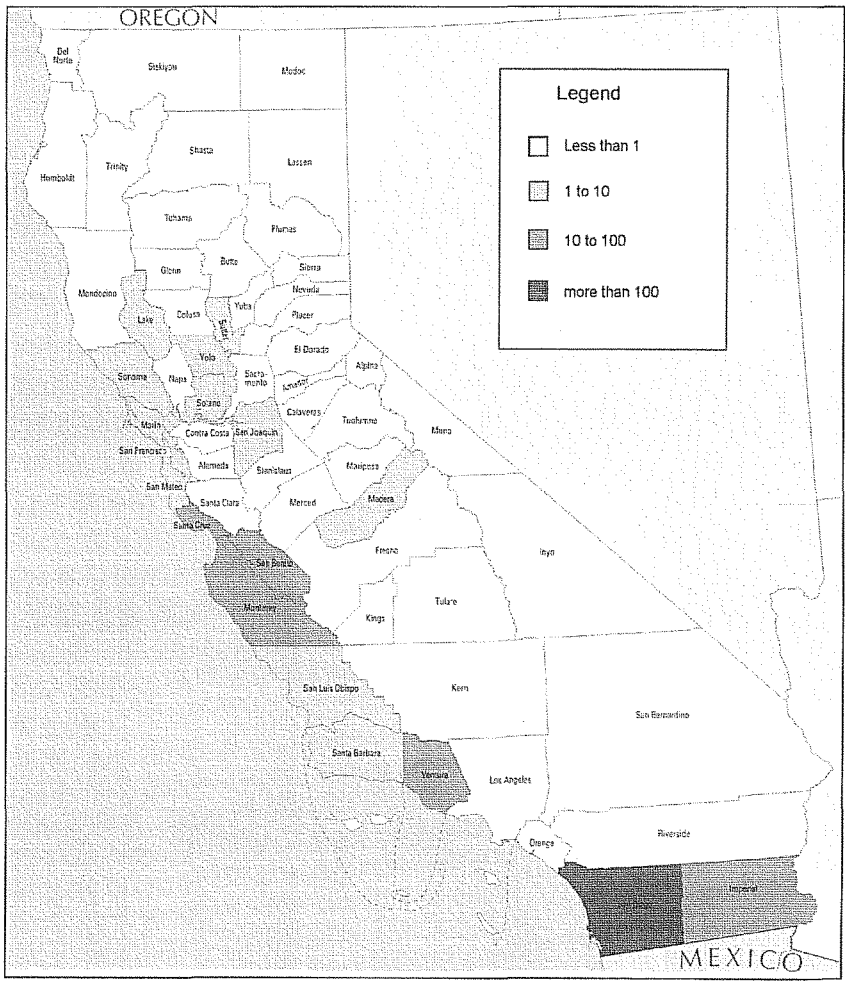


Figure 2-8. California acreage of organic Swiss chard, 2007
Source: California Department of Food and Agriculture, 2010

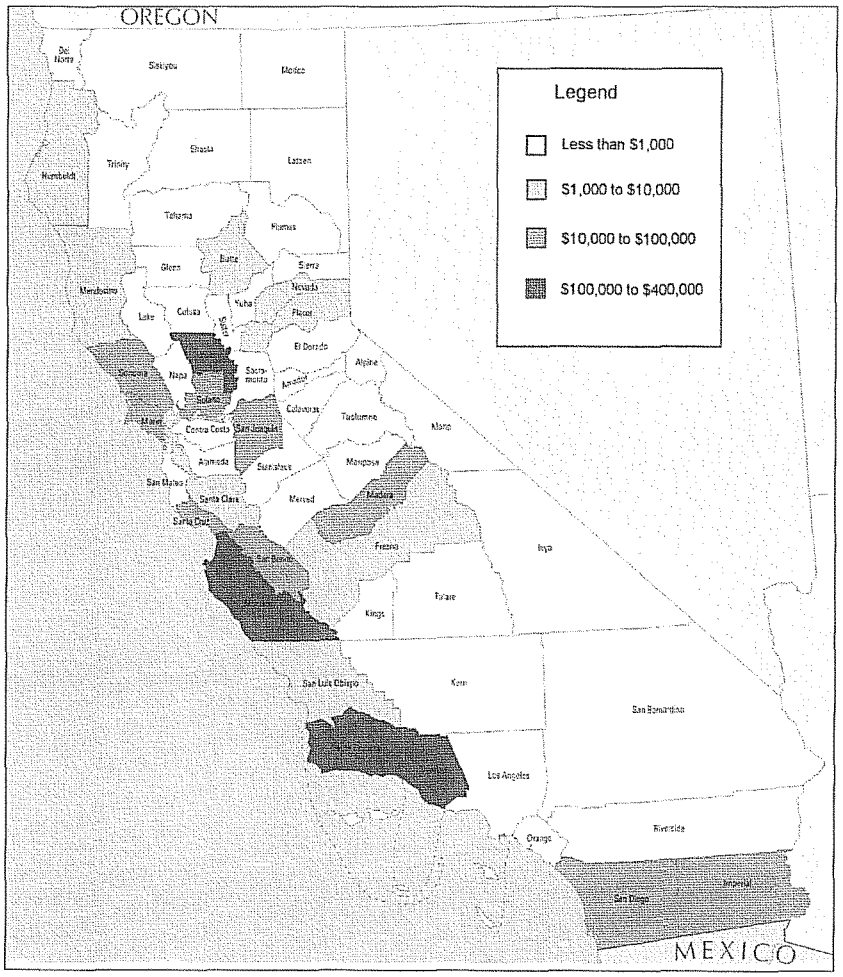


Figure 2-9. California gross sales of organic Swiss chard, 2007

Source: California Department of Food and Agriculture, 2010

2.9 NATIVE AND UNCULTIVATED NON-NATIVE BEETS

Plants that are native to a particular area or ecosystem are those that are not introduced by humans, but occur at those locations without human intervention.

Non-native beets fall into one of three categories: wild plants, weeds and feral beets. Non-native wild beets are those that that were never cultivated, and grow on their own outside of an agricultural/horticultural setting. Weeds, discussed in Section 2.5, included unwanted plants in an agricultural/horticultural setting. Feral beets are those that were originally domesticated, but have escaped cultivation and grow on their own.

2.9.1 Native beets

No native members of the genus *Beta* are found in North America (USDA, 2010a; Mansfeld, 1986, as reported in OECD, 2001, Table 3). Thus, all of the *Beta* species in North America, both cultivated and uncultivated, were introduced through human intervention from outside the continent.

2.9.2 Uncultivated wild beets in the US

Beta species in the US and potential for hybridization with sugar beet

The USDA reports two *Beta* species in the US: *Beta procumbens* and *Beta vulgaris*. Some researchers (e.g., Bartsch and Ellstrand, 1999; Bartsch et al, 2003) consider *Beta macrocarpa* as a separate species; however, USDA ARS reports that the designation was changed in 2000 to *B. vulgaris ssp. macrocarpa* (USDA/ARS, 2010a). *B. procumbens* can be artificially crossed with sugar beet (a *B. vulgaris* subspecies), but the plants usually die at the seedling stage (OECD, 2001, p. 25). In any case, *B. procumbus* in the US has been identified only in Pennsylvania, where sugar beet is not grown (USDA ARS, 2010a). Sugar beet hybridizes with all *B. vulgaris* subspecies, including *B. vulgaris ssp. macrocarpa*. The hybrids are all annuals, flowering in the first year and producing little or no root or sugar yield (Messéan et al, 2009, p. 49).

***B. macrocarpa* (or *B. vulgaris ssp. macrocarpa*).** There is some scientific disagreement about the compatibility of sugar beet and *B. vulgaris ssp. macrocarpa* (referred to hereafter as *B. macrocarpa*, the terminology in all sources except USDA/ARS 2010a). OECD reports that *B. vulgaris* and *B. macrocarpa* are fully compatible and the resulting hybrids are vigorous and fertile (OECD, 2001, p. 24). In contrast, Dr. R.T. Lewellen, a USDA, ARS geneticist who has worked with sugar beet at the USDA/ARS Salinas Research Station for many years has done

research on *B. macrocarpa* and has concluded that it does not outcross readily to sugar beet. This is because *B. macrocarpa* usually bolts and flowers too early to cause a risk of hybridization with sugar beet. Additionally, any hybrid of sugar beet and *B. macrocarpa* would possess several genetic factors that pose a challenge to the plants' survival in nature. For example, the hybrid would be mostly pollen sterile and would have disturbed genetic ratios and growth habit. Finally, because *B. macrocarpa* is self-fertile, a cross could only be made with sugar beet by using self-sterile or male sterile sugar beet plants – something which is unlikely to occur in nature (Panella, 2003).

Other researchers have also found that hybridization between *B. macrocarpa* and sugar beet is relatively rare because the flowering times usually do not overlap (Bartsch et al, 2003, p. 108; McFarlane, 1975 as reported in OECD, 2001, p. 24). In addition, based on genetic studies, Bartsch and Ellstrand (1999) report a "strong genetic differentiation between *B. vulgaris* and *B. macrocarpa*, which supports the notion that the latter is a separate species" and find it "remarkable" that hybridization between the two "is still possible" (pp. 1126 and 1129).

Sugar beets have been grown in the Imperial Valley since 1932 (Spreckels Sugar, 2009). As noted above, the earliest dated collected *Beta* specimen is from 1938; however, Bartch and Ellstrand reference observations of uncultivated wild beets in the Imperial Valley from 1928 (Bartsch and Ellstrand, 1999, p. 1126). When Bartsch and Ellstrand did their research in 1998 and found evidence of introgression between *B. macrocarpa* and *B. vulgaris* in two percent of the *B. macrocarpa* tested, sugar beets had been grown in the Imperial Valley for 66 years.

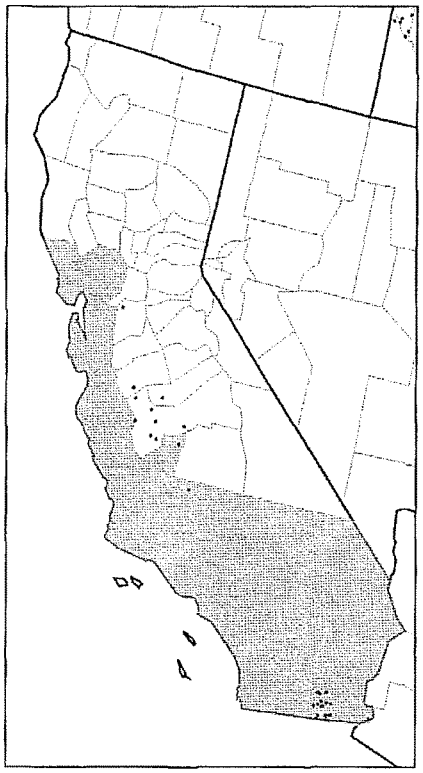


Figure 2-10. All CA counties with *beta* records
Source: Consortium of California Herbaria, 2008

Uncultivated wild beets in California

The USDA/ARS has 13 *B. vulgaris var. maritima*[30] and 7 *B. vulgaris ssp. macrocarpa* collected specimens in its National Plant Germoplasm System, all donated in 1985 by J.S. McFarlane of the USDA ARS Salinas, California office. The two *B. vulgaris ssp. macrocarpa* samples with collection information included were both from the Imperial Valley; one was collected from a sugar beet field in 1968; collection information for the other was not noted (USDA/ARS, 2010a). The Consortium of California, which keeps a database of 16 herbaria (collections of plant specimens) throughout the state, documents 172 *Beta* accessions from 15 counties, collected between 1896 and 2006 (counties show in Figure 2-10 at left) (Consortium of California Herbaria, 2008).

Forty of the specimens are designated *B. macrocarpa*, 19 as *B. vulgaris ssp. maritima*, one simply as *Beta*, and the rest are designated *B. vulgaris*. Seventeen of the accessions are from Imperial County: 14 of these are designated *B. macrocarpa*, one is designated *B. vulgaris*, and one was originally identified as *vulgaris* and later corrected to *macrocarpa*. Imperial County collection dates ranged from 1938 to 1998 (Consortium of California Herberia, 2008). Calflora's database includes herberbia records, plus other documented or recorded observations. California counties with records of *B. vulgaris* or *B. macrocarpa* are shown in Figure 2-12, along with sugar beet production areas (shown as blue dots).

[30] Specimens were originally identified as *Beta vulgaris ssp. maritima*

There have been a number of hypotheses regarding the origin of the California uncultivated wild beets, including that at least some of them are wild (feral) sugar beets (Johnson and Burtch, 1959, as referenced in Bartsch and Ellstrand, 1999, p. 1120). However, based on genetic analysis, Bartsch and Ellstrand (1999) concluded that the uncultivated wild beets in California have two independent and primary genetic origins, one from European *B. macrocarpa* (the uncultivated wild beets found in the Imperial Valley and on the Channel Islands) and one from European *B. vulgaris* (beets from all other areas in California where uncultivated wild beets are found). They found that what they termed the *B. macrocarpa* of the Imperial Valley and the Channel Islands were, with the exception of one population, "genetically identical with a Spanish *B. macrocarpa* from the Mediterranean area of Cartagena" (Bartsch and Ellstrand, 1999, p. 1126). The singe exception was a population in the Imperial Valley of *B. macrocarpa* that showed genetic similarities with *B. vulgaris*, which led them to conclude that the sugar beet (a subspecies of *B. vulgaris*) had introgressed with *B. macrocarpa* (Bartsch and Ellstrand, p. 1126). Bartsch and Ellstrand concluded that the other uncultivated wild beets in California are descended from cultivated Swiss chard and red table beets, European sea beets, and hybridized populations among these (Bartsch and Ellstrand, 1999, p. 1128).

Uncultivated beets in other sugar beet seed or root production regions

One record for uncultivated *B. vulgaris* was found for Oregon: a specimen collected in 1998 from Corvallis in Benton County, by Andrew A. Duncan (Rice, 2010). Two records for uncultivated *B. vulgaris* were found in Michigan, one of which was in Tuscola County, which is in the Great Lakes Region of sugar beet production (USDA 2010a). USDA shows five counties in western Montana with *B. vulgaris* records (Madison, Gallatin, Ravilli, Missoula, Pondera and Cascade), based on Booth and Wright's 1996 *Flora of Montana* (USDA 2010a). None of these counties are in that part of Montana included in the Great Plains Region of sugar beet production (Figure 2-2). In addition, Rice (2010), a more updated source, shows no *Beta* records for Montana (2010). While there is widespread information about uncultivated beets in California, no other information was found other than that summarized here for uncultivated beets in any other sugar beet seed or root production areas. Since these records indicate only "*B. vulgaris*" it is not possible to determine from the information whether these plants are sugar beets or some other subspecies.

In addition, USDA has previously concluded that *BetaB. vulgaris* only poses a weed issue for sugar beet crops in the Imperial Valley of California (USDA APHIS, 2005).

DEFINITIONS

Ecosystem *– the complex of a community of organisms and its environment.*

Species *– group of organisms all of which have a high degree of physical and genetic similarity, generally interbreed only among themselves, and show persistent differences from members of allied groups of organisms.*

Introduction *- intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity.*

Native species *- with respect to a particular ecosystem, a species that, other than as a result of an introduction, historically occurred or occurs in that ecosystem.*

Alien species *– with respect to a particular ecosystem, any species, including its seeds, eggs, spores or other biological material capable of propagating that species, that is not native to that ecosystem.*

Invasive species *- alien species whose introduction does or is likely to cause economic damage or environmental harm or harm to human health.*

Invasive plants *– introduced species that can thrive in areas beyond their natural range of dispersal. These plants are characteristically adaptable, aggressive, and have a high reproductive capacity. Their vigor combined with a lack of natural enemies often leads to outbreak problems.*

Sources: Executive Order 13112 – Invasive Species (1999); USDA National Agricultural Library, 2010.

2.9.3 Weed beets

Beets (genus *Beta*) generally are not weeds: there are no *Beta* species included in the Weed Science Society of America's (WSSA) list of 3,488 weeds (2010a). No *Beta* species are included among the 1,553 weeds in the USDA database of invasive and noxious weeds (USDA, 2010b).

Weed beets in European sugar beet production

We discuss the problem of weed beets in European production fields because it is a concern in Europe and may raise questions about whether the same issues may occur in the US, and, if so, what impact the use of event H7-1 sugar beet would have. Weed beets have been a serious problem in European sugar beet production since the 1970s (May, 2001; Desplanque et al, 2002; Ellstrand, 2003). In 2000, some sugar beet fields in the EU were growing more weeds than beets (Ellstrand, 2003). Weeds of the same or closely related species as the crop can present special problems. Their seeds and young plants may be indistinguishable, and they will have very similar responses to herbicides. Unlike sugar beets, the weed beets flower in the first year, and produce many seeds. Because they are the same species, any herbicide that is effective on the weed beet will also damage or destroy the sugar beet. Thus, the weed beets must be manually removed, and the grower often does not find that the weed beets are not sugar beets until they bolt. The weed beets form a seed bank that can persist for years. While weed beets and native sea beets grow in many parts of Europe, the weed beets in the production fields apparently do not originate from weeds near the production fields. In the 1990s, the

problem was traced to hybridization of weed beets with the sugar beets grown in seed production areas (Ellstrand, 2003, p. 70-73). Sugar beet and sea beet (*B. vulgaris ssp. maritima*) hybridize freely and the resulting progeny are fully fertile. Sugar beet and sea beet also share a common flowering period. Sugar beets are grown in many parts of Europe, but seed production occurs mainly in the temperate climate regions of southwest France and northeast Italy, where weed beets are also present (Bartsch et al, 2003).

While the sugar beets and weed beets introgress with each other, and the weed beets and the native sea beets that grow along much of the Atlantic European and the Mediterranean also introgress with each other, in a century of sugar beet production, gene flow from sugar beets has not altered the genetic diversity of wild sea beets in the region, including in the seed production areas (Bartsch et al, 2003).

Weed beets in the Imperial Valley

In the US, the only reports of weed beets as a problem have been in sugar beet production in the Imperial Valley (Lewellen et al, 2003; Bartsch et al, 2003; Lilleboe, 2009). The weed beet situation in the Imperial Valley is very different from that in Europe. The weed beets in Europe originated from seed production fields, where the sugar beet plants and nearby wild beets all flower at the same time, and the resulting hybrids apparently contaminated the seed supply. Thus, the European weed beets in sugar beet root production fields originated from the inadvertent planting of the weed beet seeds along with the sugar beet seeds. In the Imperial Valley, the weed beets are *B. macrocarpa*, which were present in the Imperial Valley before the introduction of sugar beets, and have coexisted with sugar beets since 1938 with very little hybridization (Bartsch and Ellstrand, 1999; Bartsch et al, 2003).

2.9.4 Feral crops

Based on available data, de-domestication has occurred in only a few crops. These feral crops are of minor importance compared with other weeds (Gressel, 2005). In North America, the feral plants that cause much of the economic damage are imported horticultural plants; for example, Japanese privet (*Ligustrum japonicum*), Japanese honeysuckle (*Lonicera japonica*) and kudzu (*Pueraria lobata*) (Gressel, 2005).

Scientists from Oregon State University report that there are no feral sugar beet crops in the US (Mallory-Smith and Zapiola, 2008, Table 1). As discussed in Section 2.5.3, in California, the only sugar beet growing state with documented beet populations (as opposed to the isolated

reports from a few other locations), genetic assessment of uncultivated wild beets has not supported the conclusion that any of these beets are feral crops.

Based on this information, and the poor competitive characteristics of sugar beets, we have concluded that the existence of feral sugar beet crops in the US is unlikely, and any that might exist are negligible.

2.10 FOOD AND FEED USES OF SUGAR BEET

In addition to producing granulated sugar, sugar beet processing facilities produce a co-product known as dried beet pulp. Pulp is the dried fiber residue left after most of the sugar has been extracted from the sliced beets. Dried beet pulp is typically sold as either a shred (with or without molasses added) or in pellet form for animal feed. Beet molasses is produced in quantities ranging from 4 percent to 5 percent of the weight of the beets and contains about 50 percent sugar. Beet molasses is used for production of yeast, chemicals and pharmaceuticals, as well as in the production of mixed cattle feeds (Southern Minnesota Beet Sugar Cooperative, 2010a).

Multiple countries that regulate the importation of biotechnology-derived crops and derived products have granted regulatory approval to event H7-1 sugar beets for food and feed uses, including Japan, Canada, Mexico, European Union, South Korea, Australia, New Zealand, China, Colombia, Russian Federation, Singapore, and the Philippines (FSANZ, 2005; Monsanto/KWS 2007; Berg 2010). Canada and Japan have also approved event H7-1 sugar beets for cultivation in those countries (Sato, 2008; CFIA, 2005).

2.11 PHYSICAL AND BIOLOGICAL ISSUES

The affected environment for land use, air quality, water quality, ecology, threatened and endangered species, and other sensitive wildlife is the area in the sugar beet root producing areas (shown in Figure 2-1) and in the seed producing region in the Willamette Valley, the seed producing region (Figure 2-4). The affected environment for climate is global, as impacts on climate change are global issue.

2.12 SOCIOECONOMICS AND HEALTH

The affected environment for socioeconomic issues includes those individuals or groups who could be economically impacted if their food, feed, or agricultural products are adversely affected by event H7-1. It also includes those who would be economically impacted if event H7-

1 becomes a regulated article: growers of event H7-1 sugar beets, sugar processors, seed companies, and sugar marketers and sugar buyers. Potential impacts to the first group are discussed primarily in Section 3.11 and impacts to the second group are discussed in Section 3.16. The potential for health impacts to individuals who may come into contact with glyphosate-tolerant sugar beets or beet seeds, or sugar or other products derived from glyphosate-tolerant sugar beets is discussed in Sections 3.11 and 3.15. Health effects of potential exposure to herbicides are discussed in Section 3.15.

Section 3 of this ER examines the possible impacts of a partial deregulation of H7-1 or similar administrative action.

3.1 PLANT PEST PROPERTIES AND UNINTENDED EFFECTS

APHIS previously determined, based on scientific analysis and in accordance with its obligations under the Plant Protection Act, that sugar beet event H7-1 is not a plant pest and does not exhibit plant pathogenic properties (USDA APHIS, 2005).

APHIS considered the potential for the transformation process, the introduced DNA sequences, or their expression products to cause or aggravate disease symptoms in sugar beet event H7-1 and its progeny or in other plants. APHIS also addressed the potential for event H7-1 to become a weed or make other plants that it breeds with into weeds.

APHIS also considered whether data indicate that unintended effects would arise from engineering of these plants. APHIS considered information from the scientific literature as well as laboratory and field data collected during the trials with event H7-1 that was provided by Monsanto/KWS in its petition (included in Schneider, 2003).

Based on the analysis summarized below, there are no impacts resulting from plant pest properties, introduced or aggravated disease symptoms, or unintended effects under any of the alternatives. Details of the Monsanto/KWS studies are included in the petition (Schneider, 2003).

3.1.1 Background

Plant genetic modification

Plant genetic modification by humans ranges from the simple approach of selection – where seeds of plants with desired traits are saved and replanted – to complex methods such as the use of recombinant DNA (rDNA; see definitions on next page). Crossing (and then recrossing) two sexually compatible plants by taking the pollen from one plant and brushing it onto the pistil of another is still the mainstay of modern plant breeding (IM/NRC, 2004). Both conventional breeding and rDNA methods can involve changes in the sequence, order, and regulation of genes in a plant and can use many of the same enzymes. However, with conventional breeding all the tens of thousands of genes in the plant are involved, and with the rDNA method only a few genes are involved. In classical breeding, crosses can be accomplished only between closely related species, and therefore only traits that are already present in those species can

be targeted. In contrast, the rDNA approach can use genes from any living organism, thus opening the door to vast potential in trait development (Lemaux, 2008, p. 774; AMA, 2000).

Other examples of plant genetic modification include cell fusion (the protective cell wall is stripped and cells are fused by some external force) and induced mutagenesis (inducing mutations in seeds by ionizing radiation or carcinogenic chemicals) (Ronald and Adamchak p. 88). Mutagenic techniques, which have been in use since the late 1920s, create random mutations and are limited by their inability to target a desired trait (FDA, 1992; Lundqvist, 2009, p. 39).

Agrobacterium

Agrobacterium tumefaciens (*Agrobacterium*) is a soil microbe that has been called "nature's own genetic engineer" because of its ability to transfer a fragment of its own DNA into a host plant (AMA, 2000). (See definitions at right.) The transferred DNA is stably integrated into the plant DNA, and the plant incorporates and expresses the transferred genes. The transferred DNA (T-DNA) reprograms the host plant cells to grow into callus tissue and produce certain amino acid derivatives that are a food source for the *Agrobacterium*. On a macro scale, the callus tissue growth is called crown gall disease. In the early 1980s scientists developed strains of *Agrobacterium* with T-DNA that lacked the disease-carrying genes ("disarmed" *Agrobacterium*). *Agrobacterium* transformation system has been utilized in the development of a large number of genetically engineered plants in commercial production (IM/NRC, 2004, pp. 28-29). The method uses a DNA molecule called a **vector**

DEFINITIONS

Nucleotide *– basic building block of nucleic acids such as DNA. Each nucleotide is made up of a nitrogen-containing group, a sugar, and a phosphate group.*

Nucleic acid *– a chain of nucleotides.*

DNA *– deoxyribonucleic acid – a type of nucleic acid that acts as the genetic material in most living things.*

Chromosome *– a DNA molecule containing all or parts of the genome of an organism, which has the ability to replicate.*

Genome *– the complete set of genes in an organism.*

Gene *– the basic unit of heredity; it is a segment of DNA on a specific site on a chromosome.*

Amino acid *– one of 20 chemical building blocks for proteins; there are also nonprotein amino acids.*

Catalyst *– a chemical that speeds up a chemical reaction but is not changed by the chemical reaction.*

Enzyme *– a biological catalyst; usually a protein.*

Recombinant DNA (rDNA) techniques *– procedures used to join together DNA segments. Under appropriate conditions, a rDNA molecule can enter a cell and replicate there.*

Mutation *– any change in the base sequence of DNA.*

Diploid *– containing two sets of chromosomes (one from each parent0.*

Sources: Sadava, 2008; IM/NRC, 2004; biology online; GMO Safety, 2010a.

that serves as a carrier to insert T-DNA that contains specific genetic elements. These genetic elements are organized into a **gene cassette,** which consists of a gene encoding for a single biological function plus other genetic elements necessary for the expression of that gene when introduced into the plant. Other elements in the gene cassette include a **promoter**, which can be thought of as the "on switch" for the gene encoding for the desired trait; and a targeting sequence, which makes sure the gene product, typically a protein, ends up in the right location within the cell (such as the chloroplast).

Unintended effects from breeding

Most crops naturally produce allergens, toxins or other antinutritional substances; these often serve the plant as natural defense compounds against pests or pathogens (FDA, 1992). Plant breeders typically monitor the levels of antinutritional substances relevant to their crop. For example, solanine is a naturally-occurring toxin produced by potatoes and is part of the plant's defense against insects and fungus. Potato breeders typically monitor solanine levels and reject lines that generate too much of it (IM/NRC, 2004).

Scientists from the Institute of Medicine (IM) and the National Research Council (NRC) ranked breeding methods according to their relative likelihood of producing unintended effects, which they hypothesized would correspond to the degree of genetic disruption associated with the method. Selection from a homogeneous population was ranked at one end of the spectrum (less likely to produce unintended effects) and induced mutagenesis (from chemicals or radiation) was ranked at the other end (more likely). *Agrobacterium* transfer of rDNA was among the methods ranked in between (IM/NRC, 2004, Figure ES-1). Recent studies in Europe comparing transgenic and conventional barley suggest that conventional breeding may cause more unintended effects than rDNA methods, likely because of the very large number of genes that are affected in conventional breeding techniques (Sonnewald, 2010). These results are consistent with those observed by APHIS with event H7-1 and many other plants produced through rDNA methods: except for the intended trait, the GE plant is found to be substantially equivalent to its non-GE counterpart.

Glyphosate tolerance

As discussed in Section 2, glyphosate acts by inhibiting the action of the enzyme 5-enolpyruvylshikimate-3-phosphate synthase, EPSPS, in plants. EPSPS is a catalyst for a reaction necessary for the production of certain amino acids essential for plant growth. When

plants are treated with glyphosate the EPSPS enzyme is inhibited, they cannot produce the amino acids needed for continued growth and eventually die. The EPSPS protein and the reaction it catalyzes are present in all plants and microbes. There are variations in the amino acid sequence of EPSPS among different plants and bacteria. Glyphosate tolerance is achieved by introducing an EPSPS enzyme, termed CP4 EPSPS, that is not inhibited in the presence of glyphosate. An *Agrobacterium* strain (designated CP4) was the source of the *cp4 epsps* gene that encodes for the CP4 EPSPS enzyme (Schneider, 2003). The CP4 EPSPS enzyme carries out the same enzymatic reaction in the plant as the native EPSPS; however, when plants that contain the CP4 EPSPS are sprayed with glyphosate, they are able to continue to produce the essential amino acids needed for plant growth. The objective of the genetic modification in event H7-1 was to simplify and improve weed management practices in sugar beet by conferring tolerance to glyphosate.

Transformation system

Event H7-1 was developed using a disarmed *Agrobacterium*-mediated transformation of a sugar beet variety used in plant breeding. Cotyledons (part of the seed embryo) derived from sterile seedlings of the diploid sugar beet line 3S0057 were used as the explant source. An explant is any portion of a plant that is to be used to initiate culture. These cotyledons were immersed in an *Agrobacterium* suspension and co-cultured for two to four days. The explants were then transferred to selective media containing 500 mg/l carbenicillin to eliminate the *Agrobacteria*. Glyphosate was used for selection of glyphosate-tolerant tissue, with tissue containing a genetic insertion to confer glyphosate tolerance assigned a unique number, such as event H7-1. After approximately seven weeks, the developed plantlets were transferred to rooting media and placed in a greenhouse. All subsequently developed event H7-1 sugar beet breeding lines and variety candidates were derived by traditional plant-breeding methods (Schneider, 2003, pp. 20-21).

DNA sequences inserted into sugar beet event H7-1

Data supplied in the petition and reviewed by APHIS (Section V.A., pp 29-44) support the conclusion that event H7-1 contains the following gene cassette:

1) a promoter from a modified figwort mosaic virus,

2) targeting sequence from the plant *Arabidopsis thaliana*,

3) the EPSPS gene from *Agrobacterium* sp. strain CP4, and

4) a portion of a gene from pea that directs genetic processing

This same gene cassette is present in other Roundup Ready® cotton and canola, which have previously been deregulated by USDA (Schneider, 2003, p. 24). The non-coding promoter is from the plant pathogen figwort mosaic virus. The promoter cannot cause plant disease and serves a purely regulatory function for the EPSPS gene. The CP4 EPSPS gene does not cause disease and has a history of safe use in a number of genetically engineered plants (e.g., corn, cotton and soybean varieties).

3.1.2 Evaluation of intended effects

Analysis of inheritance

Data was provided and reviewed by APHIS that demonstrates stable integration and inheritance of the EPSPS gene cassette over several breeding generations. Statistical analyses show that glyphosate tolerance is inherited as a dominant trait in a typical Mendelian manner (Schneider, 2003, Table V-2, pp. 45-46).

Analysis of gene expression

The level of CP4 EPSPS protein was determined from tissues collected from field trials with event H7-1 conducted at several locations. Using standard laboratory techniques, protein concentrations from H7-1 beet leaves and processed roots (brei) were determined (Schneider, 2003, Table V-3, p. 50). EPSPS proteins are ubiquitous in plants and microorganisms and have not been associated with hazards from consumption or to the environment. Crops that contain the CP4 EPSPS protein have been granted non-regulated status have included corn, soybean, cotton, rapeseed and sugar beet (USDA APHIS, 2010a). In 2009, significant acreages of corn (59 million acres or 68% of the total corn acres), upland cotton (6.3 million acres or 71% of the total cotton acres) and soybean (70.5 million acres or 91% of the total soybean acres) grown in the US were planted with herbicide tolerant varieties (USDA NASS, 2010c). Although the data include all herbicide tolerant varieties, glyphosate tolerant ones (containing CP4 EPSPS) predominate. All have also undergone FDA review (FDA, 2010).

Analysis of the intended trait

Numerous field trials were conducted in the US (Schneider, 2003, Tables VI-4 to VI-6) and in Europe (Schneider, 2003, Table VI-7) to evaluate event H7-1 in different genetic backgrounds

and in different environments. Standard field trials evaluated 1) agronomic performance, 2) disease and pest resistance performance, 3) steckling (seedling) production and 4) seed multiplication. Standard industry farming practices for the various locales was used in these trials. These practices would typically include control measures for weeds, diseases and insects. Where glyphosate was used in trials, no negative impacts from application glyphosate were noted.

3.1.3 Evaluation of possible unintended effects

Disease and pest susceptibility

In trials conducted from 1998 to 2002, qualitative and quantitative data addressing disease susceptibility and overall agronomic performance of event H7-1 were collected to assess possible effects from introduction of the CP4 EPSPS gene cassette. As summarized below, information collected from these trials indicate that event H7-1 does not alter sugar beet's susceptibility to diseases and pests. Experience in production fields since 2007 supports this conclusion.

Nursery trials in US. During the 2000 and 2001 growing seasons, quantitative data was collected from variety trials at Betaseed nurseries for comparison of varieties with event H7-1 to conventional varieties for relative resistance to four common sugar beet diseases: *Cercospora* leaf spot, *Aphanomyces* root rot, *Rhizoctonia* root rot, and curly top virus. In these trials, results of season-long testing for disease susceptibility from one to three varieties with the H7-1 event were compared with four conventional varieties. The results indicated that the disease susceptibility of the H7-1 varieties was within the range of the conventional varieties (Schneider, 2003, Section A.1).

Field trials in US. A total of 98 separate Monsanto/KWS field trials were conducted in the US from 1998 to 2002 included comparative evaluation of susceptibility to the four diseases evaluated in the nursery trials, plus several fungal seedling diseases and Rhizomania (Schneider, 2003, Section VI.A.2). Together, these are the major diseases of economic importance affecting sugar beet production in the US (Schneider, 2003, p. 60). At all but six trial locations there were no differences observed between the event H7-1 varieties and the conventional comparators. At one trial site increased susceptibility to powdery mildew was noted while at three other sites decreased susceptibility was noted. At two trial sites increased susceptibility to *Cercospora* leaf spot was also noted. Given the interactions between the environment, the genetic backgrounds of the cultivars used and some inherent genetic

variability within sugar beet varieties, these results are not unexpected and do not indicate an increased pest risk. A similar likely insignificant difference was noted in a greenhouse trial using different *Fusarium* fungus isolates. Other researchers have suggested that it may be difficult to predict field results from greenhouse/ laboratory experiments control lines or differences outside the range of conventional sugar beet norms.

Field trials in Europe. Additional field trials were conducted with event H7-1 in Europe in 1998 and 1999 and monitored for several diseases and nematode worms. No diseases or nematode symptoms were reported in any of the trials for either event H7-1 or conventional control sugar beets (Schneider, 2003, Section A.3).

Gene silencing

In evolutionary biology, a homologous trait is one derived from a common ancestor that appears in multiple species. Homology may be manifested on a macro scale, for example, in the similarity in mammal forelimbs, and on a genetic scale, in DNA sequences. Al-Kaff, et al.(1998) have noted gene silencing effects when transgenic plants have been infected by a virus with DNA sequence homology to a portion of the introduced genes. The only virus-derived DNA in the event H7-1 gene cassette is the promoter, which is from the figwort mosaic virus. None of the viral diseases of beet is related to figwort mosaic virus (Whitney and Duffus, 1986) so silencing of the EPSPS gene would not be expected, and has not been observed.

Compositional evaluation

Monsanto/KWS compared the composition of event H7-1 sugar beets with conventional sugar beets derived from the same parent line ("near isogenic control line"). To eliminate the influence of normal genetic variation between different hereditary lines and varieties, isogenic lines are usually used as a standard for comparison (GMO Safety, 2010a). The analysis of H7-1 sugar beets for compositional changes was included in Section VI.C of the petition (Schneider, 2003) and was also part of the Monsanto/KWS submission to FDA in the consultation process (See Section 3.11 for a discussion of the FDA consultation process and results). While FDA uses these data as indicators of possible nutritional changes, APHIS views them as a general indicator of possible unintended changes.

Compositional analyses evaluating carbohydrates, proteins, fiber, fat, sugars, the antinutrient saponin, and eighteen amino acids (a total of 55 statistical comparisons) in tops (leaves) and roots (brei) identified seven statistically different values compared with the near isogenic control line. All analyses fell within the range of values observed for both the near isogenic control line

and conventional sugar beet varieties, providing additional evidence that event H7-1 sugar beet does not exhibit unexpected or unintended effects (Schneider, 2003).

3.2 WEEDINESS PROPERTIES, VOLUNTEERS AND FERAL CROPS

This section addresses two questions:

1. What are the weediness properties of sugar beet?
2. Is the event H7-1 sugar beet more likely to become a weed than a conventional sugar beet?

3.2.1 Weediness properties of sugar beet

As discussed in Section 2.5, sugar beets (*B. vulgaris*) are poor competitors with both weeds and other crops (i.e., beet can compete only with members of their own species). This is discussed in Section 3.8.

3.2.2 Event H7-1 sugar beet and weediness

Some scientists, for example, Ellstrand, 2006, have raised the question of "unintended crop descendents from transgenic crops." Ellstrand states (p. 116): "The possibility of unintended reproduction by transgenic crops has raised questions about whether their descendents might cause problems. These problems have fallen into two broad categories: first, the direct feral descendents of the crops may prove to be new weeds or invasive plants, and second, that unintended hybrids between transgenic crops and other plants could lead to certain problems." This section discusses the weediness properties of H7-1 sugar beet, and addresses the concern of direct descendents of the crop that "may prove to be new weeds or invasive plants." Hybridization is addressed in several later sections.

Event H7-1 was field tested in North America from 1998 to 2003 and in Europe from 1998 to 1999. In these trials, no differences were observed between H7-1 lines and non-transgenic lines with respect to the plants' ability to persist or compete as a weed (Schneider, 2003; USDA APHIS, 2005). In these evaluations, APHIS considered data relating to plant vigor, bolting, seedling emergence, seed germination, seed dormancy and other characteristics (USDA APHIS, 2005).

In a separate evaluation, the Canadian Food Inspection Agency (CFIA), whose responsibilities include regulation of the introduction of animal food and plants (including crops) to Canada, reached the same conclusion about the weediness potential of event H7-1 compared with non-

transgenic sugar beet. In 2005, the CFIA authorized the "unconfined release into the environment and livestock feed use of the sugar beet event H7-1" (CFIA, 2005). In its evaluation of event H7-1, CFIA "determined that germination, flowering, root yield, susceptibility to plant pests and diseases typical to sugar beet and bolting percentage were within the normal range of expression of these traits currently displayed by commercial sugar beet hybrids" (CFIA, 2005). The CFIA reached the following conclusions (CFIA, 2005):

> No competitive advantage was conferred to these plants, other than that conferred by tolerance to glyphosate herbicide. Resistance to Roundup® agricultural herbicides will not, in itself, render sugar beet weedy or invasive of natural habitats since none of the reproductive or growth characteristics were modified.
>
> The above considerations, together with the fact that the novel traits have no intended effects on weediness or invasiveness, led the CFIA to conclude that the H7-1 sugar beet event has no altered weed or invasiveness potential compared to currently commercialized sugar beet.

Thus, the potential for event H7-1 to become a weed or invasive plant was determined to to be no greater than conventional sugar beets. Neither sugar beets or other beta species plants are considered a weed issue in any state other than California.

3.2.3 Sugar beet volunteers

Volunteers, which are plants from a previous crop that are found in a later crop, may result from bolters or groundkeepers. Refer to Section 2.3.4 for a detailed discussion.

Root production

While several scientists have reported that volunteer glyphosate tolerant plants could in theory become a problem in rotational crops when both rotational crops are glyphosate tolerant, none provided specific information or data relevant to sugar beets (e.g., Cerdeira and Duke, 2006; Owen and Zelaya, 2005; York et al, 204; NRC, 2010). Since sugar beet is grown for the vegetable and not the seed, volunteers in a root crop could occur only from the rare plant that has bolted, if it is allowed to go to seed. Groundkeepers are cold sensitive and only rarely survive winter conditions in most sugar beet production areas (Grant, 2010,p. 7; Cattanach et al, 1991; Panella, 2003).

As discussed in Section 2.3.4, bolters deplete the sugar content of the root and cause problems with harvesting. Thus, good management practices and the grower's own interest dictate removal of bolters. Sugar beet varieties are specifically bred to make bolters rare. Volunteers

are unlikely even if bolters are not removed because a series of unlikely events must each coincide to produce volunteers. If a bolter is not removed, it must be pollinated by another bolter, and be allowed to go to seed; the seed must then survive the winter freeze and germinate. And even if this does occur, the resulting volunteer would need to successfully compete with the next year's crop, and could be controlled by mechanical means or by several registered herbicides other than glyphosate that can be used on sugar beet volunteers (Meister, 2009). Depending on the rotation crops chosen to follow sugar beet (in the normal 3-4 year rotation), growers can use tillage and/or herbicides. Examples of some herbicides are methylsulfuron methyl, 2,4-dichlorophenoxyacetic acid (2,4 D) and 3,6-dichloro-o-anisic acid (dicamba) for the control of any volunteers prior to planting and after crop emergence.

Seed production

Control of volunteers is more of a concern with seed production, for both conventional and event H7-1 sugar beet, to maintain seed purity. As discussed in Section 2.7.3, WCBS and Betaseed control all seed production in the Willamette Valley. WCBS has detailed requirements in it protocol (in Appendix B of this ER) for post-harvest field management. After harvesting, the fields are shallow tilled and irrigated to promote sprouting of shattered seeds (unless sufficient rainfall to promote sprouting has occurred). Fall plowing is not allowed. After the seed is allowed to sprout, it is controlled by herbicides or other means. All equipment is cleaned according to WCBS procedures before it leave the fields. Fields used for growing event H7-1 are inspected by WCBS "for a minimum of five years or until no volunteers are noted (Appendix B). Betaseed has similar requirements.

3.2.4 Impact summary

Alternative 1

Under Alternative 1, there would be no impact from event H7-1 1 on weediness or volunteers.

Alternative 2

Weediness properties. Based on the information summarized in the subsection, APHIS has concluded that sugar beet does not exhibit weediness properties, and that event H7-1 does not exhibit any altered weediness properties when compared with conventional sugar beet. Therefore, Alternative 2 would not impact the weediness characteristics of sugar beet.

Feral crops. As explained in Section 2.9, the existence of feral sugar beet crops in the US is highly unlikely, and any population that may exist would be negligible. Because there are no

known or suspected feral crops of sugar beets in the US, Alternative 2 would not impact feral sugar beet crops.

Volunteers in root crop fields. Volunteers resulting from root crops are generally not a concern because the crop is harvested in the vegetative stage, bolters are generally rogued (removed), and the occasional volunteer would be unlikely to survive the winter freeze and could be controlled by other means than glyphosate. The interim measures further reduce the potential for any volunteers resulting from a root crop by requiring complete control of bolters. Under the proposed interim measures, all event H7-1 root crop growers will have measures in place that require them to survey, identify, and eliminate any bolters in their root crop fields before they produce pollen or set seed (Item 5). Therefore, no or negligible impacts from event H7-1 volunteers in root crop fields would be expected under Alternative 2.

Volunteers in seed production fields. Managing volunteers in seed production fields is an important part of seed growers' efforts to maintain seed purity. WCBS and Betaseed have protocols in place to force same-year sprouting of seed left behind in the production field, plus long-term monitoring (five years for WCBS) of production fields to identify and remove any volunteers. The interim measures contain a universal requirement to force same-year sprouting, of any event H7-1 seed left behind in the production field, and subsequent removal and destruction of plants (Item 4.j); 3-year monitoring of fields for volunteers along with removal and destruction (Item 4j); employee training (Item 4k); recordkeeping to document compliance (Item 4m); and third-party audits for compliance (Item 7). Given the existing industry standards coupled with the mandates of the interim measures to control volunteers, no or negligible impacts from event H7-1 volunteers in seed production fields would be expected under Alternative 2.

3.3 IMPACTS OF EVENT H7-1 SUGAR BEET ROOT CROPS ON CONVENTIONAL SUGAR BEET CROPS

This section considers the possibility of impacts from event H7-1 sugar beet crops on conventional sugar beet crops through gene flow (refer to Section 2.4 for a general discussion of gene flow), or by mixing in harvesting, transportation, stockpiling, or processing.

3.3.1 Pollen sources in production fields

As discussed throughout this document, in production fields sugar beets are grown for their roots and are harvested before they flower. The only sources of event H7-1 pollen in production

fields would be from uncontrolled bolters. Refer to Section 2.3.4 for a detailed discussion of bolting.

3.3.2 Potential for gene flow in root production fields

Because sugar beets are harvested in the vegetative stage, before they flower, there is little potential for cross-pollination between root production fields. Cross-pollination, if it occurred could potentially result in adventitious (inadvertent) presence of genetic material from the crop in one field into a nearby crop's field. Scientists from Oregon State University report that for sugar beet "gene flow via pollen or seed in root production fields is generally not an issue" (Mallory-Smith and Zapiola, 2008, p. 433). Messéan et al concur: "the potential for adventitious presence of GM material in non-GM sugar beet production is low through cross-pollination since the harvest is vegetative" (2009, p. 49). The European Commission (the executive body of the European Union [EU]) Scientific Committee on Plants (2001) also assessed the potential for adventitious presence of event H7-1 sugar beet at various stages of farm production. The Committee identified seed production as the major potential source of adventitious presence, with other sources, including planting, cultivation, cross-pollination, volunteers, harvesting and production all with no or minor potential contributions (p. 8).

Because pollen dispersal is a concern with sugar beet seed production, it is discussed in detail in the analysis of impacts in seed production (Section 3.9). The Section 3.9 discussion evaluates distances over which cross pollination may occur; this is an issue with little relevance to root production.

3.3.3 Potential for mixing of event H7-1 and conventional sugar beets

As discussed in Section 2.2, 95 percent of sugar beet seeds planted in the US in 2010 were glyphosate-tolerant. Except in California, where only conventional sugar beet has been grown to date, production, processing and marketing within the industry no longer distinguishes between event H7-1 and conventional sugar beet crops—they are processed and marketed together. The 22 sugar beet processing facilities in the US process a combination of event H7-1 and conventional sugar beets. As discussed in Section 2.3, no currently operating sugar beet processing facilities have been built in the US since 1975. Because a processing facility is required for sugar production, the 22 processing facilities account for all the beet sugar produced in the US. Markets have been available for the sugar, beet pulp, molasses and other products (Kaffka and Hills, 1994, p. 2; California Beet Growers Association, 1998; Western Sugar Cooperative, 2006a; Michigan Sugar Company, 2010b; American Crystal Sugar

Company, 2009; Minn-Dak Farmers Cooperative, undated; Snake River Sugar Company, 2009).

3.3.4 Consequences of gene flow in production fields

We have found no reports of cross-pollination between event H7-1 sugar beet root production fields and conventional sugar beet crops since event H7-1 sugar beets were first grown in production fields in limited quantities the US in 2006. As discussed above, because sugar beets are harvested in the vegetative stage, bolters are uncommon, and it is good management practice to remove bolters, pollen movement, or gene flow between event H7-1 and conventional crops is expected to be minimal.

If bolters occurred in two nearby fields, one with event H7-1 and one with conventional sugar beets, and the bolters were not controlled and were allowed to flower, a conventional plant could potentially become fertilized with event H7-1 pollen, and the resulting seeds may contain the event H7-1 trait. This occurrence would not affect the conventional sugar beet crop because it would be harvested before these new resulting seeds grew into sugar beet plants, if they did. If the seeds germinated and the resulting plants survived the winter, which is unlikely in most sugar beet production areas, the volunteer plants would appear in the conventional sugar beet farmer's next rotational crop, and (if they survived) would be treated as weeds, as described in Section 3.3, and would be eliminated.

There is evidence that growers pay close attention to bolters. All growers that submitted declarations in the sugar beet litigation declared that bolters are easy to spot in their fields and if seen they would destroy them. There is no evidence that we have seen to the contrary. Any conventional sugar beet grower concerned about this occurrence could prevent it by controlling bolters in his sugar beet crop, which is normally stewardship for any sugar beet crop.

3.3.5 Potential consequences from mechanical mixing

With the exception of the Imperial Valley where only conventional sugar beets have been grown, grown, commingling of harvested beets from H7-1 seed and conventional seed has occurred since 2007, with no consequences.

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3.3.6 Impact Summary

Alternative 1

Under Alternative 1, there would be no gene flow impact from event H7-1 root crop production to conventional sugar beet crops.

Alternative 2

Gene flow. Even without the interim measures, impacts from event H7-1 sugar beet root crops to conventional sugar beet root crops have not occurred and would not be expected because: 1) sugar beets are harvested in the vegetative stage, before they flower; 2) if bolting and cross-pollination occurred in nearby fields, the root crop would not be affected; 3) any conventional grower who wanted to be certain of preventing cross pollination could do so by controlling bolters in his own root production fields; 4) a volunteer event H7-1 hybrid appearing in a subsequent crop resulting from cross pollination in root production fields can be controlled using standard weed control practices and would not likely survive the winter in most growing areas in any event.

The interim measures further reduce the potential for gene flow from event H7-1 root crops to conventional root crops by requiring complete control of bolters. Under the proposed interim measures, commercial event H7-1 root crop growers will have measures in place that require them to survey, identify, and eliminate any bolters in their root crop fields before they produce pollen or set seed (Item 5). Item 6 of the interim measures requires event H7-1 processors or cooperatives to survey, identify, and eliminate any bolters in outdoor storage before they produce pollen or set seed. Therefore, no or negligible impacts from gene flow from event H7-1 sugar beet root crops to conventional sugar beet root crops would be expected under Alternative 2.

Mixing of harvested beets. Currently, by mutual agreement among growers, cooperatives, processors and marketers, event H7-1 sugar beets and conventional sugar beets are harvested, transported, stockpiled, processed and marketed without distinction in all areas except California, where event H7-1 sugar beet has not been grown. No impacts have occurred and none are expected. Through the interim measure (Item 1) prohibiting planting of event H7-1 in California, this status quo will be maintained. Therefore, under Alternative 2, no impacts are expected resulting from mechanical mixing of event H7-1 and conventional sugar beets.

3.4 IMPACTS OFOF EVENT H7-1 ROOT CROPS ON ORGANIC SUGAR BEET CROPS

Based on all available information, we have concluded that there is essentially no organic sugar beet production in the US. The only reference to organic sugar beet production we found was from the State of California, where 0.02 to 0.03 acre of sugar beet production in Los Angeles County was reported from 2002 to 2007, with most recent annual sales of five dollars (California Department of Food and Agriculture, 2010). California is by far the largest producer of organic commodities in the US, accounting for approximately one-third of sales in 2008 (USDA, 2010c, Table 1). USDA tracks production of a number of organic crops, but not organic sugar beets. Although no other information was found, similar production may be occurring in other states.

We have found no other information about organic sugar beet production in the US. As discussed in Section 2.3, all the commercial sugar beet grown in the US is processed into sugar at one of the 22 processing facilities, none of which process organic sugar beets.

3.4.1 Impact summary

Based on the above discussion, neither alternative would be expected to result in impacts to organic sugar beet production, because there is essentially zero organic sugar beet production in the US.

There is a substantial European organic sugar beet business, and American organic farmers may in the future decide to grow organic sugar beets. This would most likely be small-scale production, as no processing facility would be available. The presence of event H7-1 sugar beet would not inhibit the development of an organic sugar beet industry. As discussed in Section 3.4, a grower of organic sugar beets could ensure no cross-pollination from event H7-1 fields by controlling any bolters in his sugar beet crop. As discussed in Section 3.9, organic sugar beet seed is available from European suppliers. Therefore, Alternative 2 is not expected to result in impacts to organic farmers who may choose to grow sugar beets in the future.

3.5 IMPACTS OFOF EVENT H7-1 ROOT CROPS ON OTHER *BETA* (NON-SEED) CROPS

The cultivated forms of *B. vulgaris*, including sugar beet, red table beet, Swiss chard, and spinach (leaf) beets are all varietal members of the subspecies *vulgaris* (*B. vulgaris* ssp. *vulgaris*) (OECD, 2001, Table 2). They are all biennial and all are sexually compatible with sugar beets (OECD, 2001). Whether grown for leaves or roots, beet crops are all harvested in their first year before they produce seed. In addition, as discussed in Section 2.8.1, there is

virtually no overlap between sugar beet root production areas and major areas of production of other *Beta* crops.

Most growers purchase seed for their table beet crops; however, a few organic gardeners may allow part of their crop to vernalize then to go to seed and then save the seed for replanting. If a sugar beet production root crop was grown close to a table beet crop that was allowed to go to seed and the sugar beet crop had uncontrolled bolters that flowered at the same time as the other beet crop, there would be some very small potential for hybridization between the sugar beet and other beet. Based on the discussion in Section 3.3, this occurrence would be expected to be exceedingly rare and unlikely to occur. The situation would be no different for event H7-1 or conventional sugar beet. There is no indication that this has occurred since wide scale H7-1 beet root production began in 2008.

3.5.1 Impact summary

Alternative 1

Under Alternative 1, there would be no impacts from event H7-1 root crop production on other *Beta* crops.

Alternative 2

Assuming no interim measure provisions, impacts from event H7-1 sugar beet root crops to conventional sugar beet root crops have not occurred and would not be expected because: 1) sugar beets are harvested in the vegetative stage, before they flower; 2) if bolting and cross-pollination occurred between event H7-1 and other *Beta* vegetable crops, the harvested crop would not be affected; 3) any grower of *Beta* vegetable crops who wanted to be certain of preventing cross pollination could do so by controlling bolters in her own vegetable crop fields; 4) a volunteer event H7-1 hybrid appearing in a subsequent crop resulting from cross pollination can be controlled using standard weed control practices and 5) major production of sugar beet root crops and other *Beta* vegetable crops do not coincide. In addition, among the sugar beet production areas, organic *Beta* vegetable growers, who may sometimes save their own seed, are concentrated in California, where only conventional sugar beet is grown.

The interim measures further reduce the potential for gene flow from event H7-1 root crops to other *Beta* vegetable crops by requiring complete control of bolters. Under the proposed interim measures, all event H7-1 root crop growers will have measures in place that require them to survey, identify, and eliminate any bolters in their root crop fields before they produce pollen or

set seed (Item 5). Item 6 of the interim measures requires event H7-1 processors or cooperatives to survey, identify, and eliminate any bolters in outdoor storage before they produce pollen or set seed. Therefore, no or negligible impacts from gene flow from event H7-1 sugar beet root crops to other *Beta* vegetable crops would be expected under Alternative 2. The prohibition on growing event H7-1 in California (interim measure Item 1), where the majority of the organic *Beta* vegetable crops in sugar beet production areas is grown, will further reduce the potential for any impact.

In the multiple years of cultivation to date of GT sugar beet on a wide scale, there are no indications that gene flow has occurred.[31]

3.6 IMPACTS OF EVENT H7-1 SUGAR BEET ROOT CROPS ON OTHER *BETA* SEED PRODUCTION AREAS

As discussed in Section 2.8, nearly all red table beet and Swiss chard seed production occurs in western Washington State and in California, where event H7-1 sugar beet root crops are not grown. A small amount of red table beet and Swiss chard seed production occurs in the Willamette Valley, where sugar beet root crops are not grown. Spinach beet seed production, if it exists separately from red table beet and Swiss chard production, is apparently very small.

3.6.1 Impact summary

Alternative 1

Under Alternative 1, there would be no impacts from event H7-1 production on other *Beta* crops.

Alternative 2

Even without the interim measures, impacts from event H7-1 sugar beet root crops to seed production areas for red table beets and Swiss chard (other *Beta* seed crops) have not occurred and would not be expected because: 1) sugar beets are harvested in the vegetative stage, before they flower; 2) seed production for red table beets and Swiss chard does not occur in or near the same geographic areas as event H7-7 sugar beet root production.

Even if the unlikely event there were isolated areas of other *Beta* seed crops outside the main production areas (seed savers) and near sugar beet root crops, the interim measures further reduce the potential for gene flow from event H7-1 root crops to other *Beta* seed crops by requiring complete control of bolters. Under the proposed interim measures, all event H7-1 root

[31] Hofer Decl. (Dkt. #48) ¶ 14; Berg Decl. (Dkt. #39) ¶ 15; Grant Decl. (Dkt. #45) ¶ 18; Lehner Decl. (Dkt. #252) ¶ 6.

crop growers will have measures in place that require them to survey, identify, and eliminate any bolters in their root crop fields before they produce pollen or set seed (Item 5). Item 6 of the interim measures requires event H7-1 processors or cooperatives to survey, identify, and eliminate any bolters in outdoor storage before they produce pollen or set seed. Therefore, no or negligible impacts from gene flow from event H7-1 sugar beet root crops to other *Beta* seed crops would be expected under Alternative 2. The prohibition on growing event H7-1 in California and the Western Washington counties where the majority of the US red table beet and Swiss chard seed production occurs (interim measure Item 1), will further reduce the potential for any impact. In the multiple years of wide scale cultivation of H7-1 sugar beets, there have been no indications that that any gene flow has occurred [32]

3.7 IMPACTS OF EVENT H7-1 ROOT CROPS ON NATIVE BEETS

As discussed in Section 2.9, no native members of the genus *Beta* are found in North America. Therefore, gene flow to native beets will not occur under either alternative.

The absence of native *Beta* plants in North American is an important difference for sugar beet production concerns (both event H7-1 and conventional) from other regions of the world, in particular, the EU, where "[i]t is considered essential to preserve the diversity of sea beet [wild *B. vulgaris ssp. maritima*] for any long term plant breeding strategy, and for conservation and study in its own right" (Messéan et al, 2009, p. 40).

3.7.1 Impact summary

Because there are no native beet populations in the US, there would be no impact with either alternative.

3.8 IMPACTS OF EVENT H7-1 CROPS ON NON-NATIVE WILD AND WEEDBEETS

Non-native wild and weed beets are described in detail in Section 2.9. Except for isolated reports in Michigan and Oregon, all the known populations of non-native wild and weed beets in sugar beet root production states occur in California, where event H7-1 sugar beets are not grown. As discussed in Section 2.9, *B. macrocarpa* weed beets are a weed issue in the Imperial Valley, the only major sugar beet production area in California. Even so, research in 1998 found only minor introgression between the sugar beets and *B. macrocarpa* after 66 years of coexistence in the Imperial Valley (Bartsch and Ellstrand, 1999).

[32] Hofer Decl. . (Dkt. . #48) ¶ 14; Berg Decl. . (Dkt. . #39) ¶ 15; Grant Decl. . (Dkt. . #45) ¶ 18; Lehner Decl. . (Dkt. . #252) ¶ 6.

3.8.1 Impact summary

Alternative 1

Under Alternative 1, there would be no effect of gene flow from event H7-1 to non-native wild or weed beets.

Alternative 2

APHIS has previously concluded that there are no issues with weed beet populations in the U.S. outside California. Within the states where event H7-1 root crops are grown, there are reports of non-native wild beets from Montana, Oregon and Michigan. The reports from Montana are dated; more recent data do not indicate the presence of non-native wild or weed beets in Montana. Also, the report was from a part of Montana where sugar beets root crops are not grown. The single report from Oregon is from an area where sugar beet root crops are not grown. One of the Michigan reports was from a county where sugar beet crops are produced. No additional information was found, and weed beets are not reported as a weed problem in sugar beet root production in Michigan (Michigan Sugar Company, 2009). Based on the absence of any information about any uncultivated beet populations in Michigan (and the challenges in surviving winter) non-native wild or weed beet populations are expected to be nonexistent or minor. The only potential for impact from a sugar beet root crop would be by gene flow from an uncontrolled bolter, assuming any non-native wild or weed beet is close enough to the bolter and flowering at the same time, so that it might be pollinated. Based on this information, the potential for impact from sugar beet root production crops on non-native wild or weed beets appears to be negligible. It would be non-existent with the proposed interim measures. Under the proposed interim measures, all event H7-1 root crop growers will have measures in place that require them to survey, identify, and eliminate any bolters in their root crop fields before they produce pollen or set seed (Item 5). Item 6 of the interim measures requires event H7-1 processors or cooperatives to survey, identify, and eliminate any bolters in outdoor storage before they produce pollen or set seed In the multiple years of H7-1 cultivation to date, there have been no issues identified with wild or weed beets.

Non-native wild and weed beet populations exist in California. However, no event H7-1 commercial crops have been grown in California, and Item 1 of the interim measures prohibits growing event H7-1 crops in California.

Therefore, under Alternative 2, no impacts to non-native wild or weed beets would be expected.

3.9 IMPACTS OF EVENT H7-1 SEED PRODUCTION ON CONVENTIONAL SUGAR BEET AND OTHER *BETA* SEED CROPS

It is possible, without proper stewardship, for cross-pollination and gene flow between crop types during seed production, because that is where pollination happens. Also, absent appropriate stewardship measures, physical mixing of seeds is possible during harvesting, seed cleaning, packaging and transport.

3.9.1 Maintaining seed purity, identify and quality

The Federal Seed Act and its implementing regulations[33] establish basic standards for certification of seed, which are carried out by state seed certifying agencies. A state seed certifying agency is created by state law, has authority to certify seed, and has standards and procedures approved by USDA "to assure the genetic purity and identity of the seed certified." Seed certifying agencies' standards and procedures must meet or exceed those specified in the USDA regulations.[34]

However, sugar beet seed is generally not certified, and seed companies have established their own standards, as described in Section 2. There are certified wheat, soybean and corn seed growers who produce their seed to sell to farmers for planting their commercial crops. This issue is not relevant in sugar beets, because none of the sugar beet root growers harvest any sugar beet seed. All sugar beet seed producers sell all of their seed to seed companies to be sold to farmers. Even if sugar beet root growers could save some seed, they have no means for processing it (so it would work in a planter) and providing the appropriate seed treatments and would never take the risk of trying to plant it because of the uncertainty of what they have.

While sugar beet seed is generally not certified, the Oregon Seed Certification Service (OSCS) standards for certified seed and the corresponding isolation distances are reported here, as additional data points on what to expect in seed purity from a given isolation distance. The OSCS has set the following standards for those items for certified sugar beet seed (OSCS, 1993):

- Pure seed, minimum: 99.00%
- Other crops, maximum: 0.10%
- Inert matter, maximum: 1.00%

[33] 7 C.F.R. §CFR 201
[34] 7 U.S.C. §USC 1551(a)(25) and 7 C.F.R. §CFR 201.67

- Weed seed, maximum: 0.10%

Minimum isolation distances required for certified seed are as follows (OSCS, 1993):

- From sugar beet pollen of similar ploidy or between fields where male sterility is not used – 2,600 ft (0.49 mile)
- From other pollinator or genus *Beta* that is not a sugar beet – 8,000 ft (1.5 mile)

The maximum specified OSCS required isolation distance for sugar beet seed production is 10,200 ft (1.9 miles, from other, non-sugar beet *Beta* species) for "stock" seed which has a maximum allowable concentration of "other crop" seed of 0.00% (OSCS, 1993).

3.9.2 Summary of practices for sugar beet seed production

All of the sugar beet seed in the Willamette Valley is produced by either West Coast Beet Seed Company (WCBSC) or by Betaseed (see Section 2.7 of this ER). WCBSC has developed explicit standard operating procedures and grower guidelines that are intended to minimize and/or eliminate the possibility of pollen-flow between fields of related Beta species (See Section 2.7 and Appendix B). Both WCBS and Betaseed belong to the Willamette Valley Specialty Seed Association (WVSSA) and follow the guidelines for isolation and minimum separation distances between fields (Appendix A). The minimum isolation distance from event H7-1 ("GMO") sugar beet and all other open pollinated Beta crops, in both the WCBS protocol and the WVSSA guidelines is four miles. All growers of commercial specialty seed in the Willamette Valley are members of the WVSSA (Loberg, 2010). This includes all commercial companies raising Beta species. The isolation distances required by WVSSA between Event H7-1 sugar beets and other Beta species such as chard or table beets is 2.1 miles further than the maximum required OCCS isolation distance for stock seed discussed above.

Principles of quality assurance for sugar beet seed production have been set forth in an industry-endorsed Code of Conduct (Appendix C). The Sugar Beet Code of Conduct adopted by the beet group of the International Seed Federation (ISF) describes the measures the sugar beet seed industry has taken to deliver high quality varieties, including measures to minimize adventitious presence of transgenic sugar beet seed in non-transgenic Beta seed. The Code of Conduct document has been agreed on by Syngenta Seeds, SESVanderHave, Danisco Seed, Fr. Strube Saatzucht KG, A. Dieckmann-Heimburg, KWS (owns Betaseed), and affiliated companies.

3.9.3 Sugar beet seed production since 2007

Commercial H7-1 sugar beet seed has been produced since 2005, with the first major seed production year in 2006. The total acreage of H7-1 sugar beet in the Willamette Valley since 2008 has been between 4000 and 5000 acres (Gabel, 2010, p. 7; Pierson, 2010, p.10). Only one grower who sells organic beet or chard seed has been identified in the Willamette Valley. That grower produced chard seed on approximately 1-3 acres at the Western margin of the Willamette Valley. He has tested his organic chard seed using a PCR test capable of detecting 0.01% GE content during this period (Morton, 2010, 61:15-62:6). That seed has been tested each year since 2007 and to date has not detected the presence of any H7-1 sugar beet. (Hoffman, 2010a, p. 15; Morton, 2010, 36:8-17, 75:19-77:13, 99:6-21, 112:10-14; Stearns, 2010, 40:4-15, 49:6-16).

In May 2009, an incident was reported involving event H7-1 steckling disposal that raised questions regarding one sugar beet seed company's stewardship and disposal requirements for those materials (Roseboro, 2009). Stecklings are sugar beet roots that may be transplanted into hybrid sugar beet fields. In or around May 2009, the Pro Bark garden store in Corvalis, Oregon procured a quantity of peat moss from Betaseed. Betaseed had used the peat moss to transport a shipment of sugar beet stecklings, and after the shipment had been transplanted, some quantity of stecklings remained in the peat moss. After Pro Bark obtained the peat moss Pro Bark mixed it with potting soil and offered it for sale as a fertile soil mixture. Betaseed learned that the mix was being sold and that it contained some stecklings, and at that point, Pro Bark's records indicated that it had sold portions of the mixture to thirty customers located in the Corvalis and Albany area. Betaseed repossessed the portion of the mixture that had not been sold. Betaseed personnel visited twenty of the thirty customers who had purchased portions of the mixture and removed any stecklings or steckling fragments found in the mixture. The owner of Pro Bark contacted seven additional purchasers and requested that they inspect for and destroy any stecklings they had purchased (Lehner 2010, pp 7-10.)

Betaseed reported that the stecklings found in the mixture after repossessing it were not likely to survive and produce pollen. Most of the stecklings were fragmented, rotting or dead. Also, because a large percentage of Betaseed hybrid sugar beet fields in the Willamette Valley in 2009 had the event H7-1 gene only on the non-pollinating female plant (see Section 2.7), the shipment of stecklings that Betaseed had transported in the peat moss was composed of less than 5% H7-1 male pollinators. Therefore, according to Betaseed, the chances that any steckling in the peat moss was intact, alive and a male H7-1 pollinator were remote. In addition, given the time of year when the fertile mixture was sold, cross-pollination would have been very

unlikely even if the stecklings had been able to produce pollen, and there were no subsequent reports of any cross-pollination from the stecklings. Betaseed subsequently revised its Standard Operating Procedures to provide for proper disposal of the peat moss in which it transports stecklings (Lehner, 2010, pp. 7-10).

3.9.4 Measured sugar beet pollen dispersal

Many studies have been done to measure distances over which cross-pollination may occur in *Beta* species, with a range of results (e.g., Bartsch et al, 2003; Chamberlain, 1967; Darmency et al, 2009; Darmency et al, 2007; Fenart et al, 2007). Darmency et al (2009) summarized a literature review of studies on pollen flow in sugar beet (values reported in meters converted to feet):

Authors	Maximum dispersal
Alibert et al (2005)	2.1% at 700 ft
Archimowitsch (1949)	0.3% at 2,000 ft
Bateman (1947)	0.07% at 62 ft
Brants et al (1992)	8% at 250 ft
Dark (1971)	0.1% at 100 ft
Dark (1971)	3,900 ft max (using a pollen trap, not hybrid seed production)
Darmency et al (2007)	1.3% at 920 ft
Jensen and Bogh (1942)	2,600 ft max (using a pollen trap, not hybrid seed production)
Madsen (1994)	0.31% at 250 ft
Saeglitz et al (2000)	40% at 660 ft
Scott and Longden (1970)	26 ft max (using a pollen trap, not hybrid seed production)
Stewart and Cambell (1952)	10% at 50 ft
Vigouroux et al (1999)	1.2% at 50 ft

Note: The maximum dispersal was "the highest rate at the farthest distance to which pollen or hybrids were found in the study".

Darmency et al (2009, p. 1085) note that the experiments "were hardly comparable because the experimental design varied widely." The researchers also found that nearly all fertilization from pollen source occurs near the field (within about 0.3 miles). The summary table does not make distinction between mere pollen presence and actual hybridization, which, as discussed previously, can be very different. Darmency et al did not report how many, if any, of these studies used isolated bait plants rather than groups of receptor plants that would be producing their own pollen cloud, which, as discussed above, could make a substantial difference (i.e., the percentages of pollination by an outside source are much smaller with competition). Also, in their own experiments, even when the pollen reached the target plant and hybridization did

occur, Darmency et al found a large drop in germination rates in seeds produced by plants removed from the source, with approximately 40 percent at the source dropping to one percent at around 1,000 feet from the source (2009, p. 1087).

3.9.5 Modeled sugar beet pollen dispersal

Research scientists specializing in modeling pollen dispersal have modeled the sugar beet pollen dispersal for outcrossing to the organic *Beta* production field of a Plaintiff's declarant who believed his fields would be cross-pollinated by event H7-1. The nearest event H7-1 field was 6.9 miles distant. Using conservative assumptions and modeling conditions for the three days during the "pollen shed" period when wind conditions were most likely to result in cross-pollination (June 22, 23, and 27), the modelers obtained the following results for likelihood of outcrossing: June 22, 1 in 4.9 million; June 23, one in 1.1 billion; and June 27, 1 in 222 million. The risk of any successful pollination in these circumstances is highly remote.

3.9.6 Site-specific assessment of cross-pollination potential in the Willamette Valley

This discussion focuses on the Willamette Valley because it is the only known location where event H7-1 commercial seed production and commercial seed production of Swiss chard and red table beet coexist. At least three qualified scientists have evaluated the potential for gene flow from event H7-1 to other *Beta* seed crops in the Willamette Valley: Mark Westgate, PhD, whose results are summarized above; Neil Hoffman, Ph.D. and Leonard Panella, Ph.D. Westgate is a professor of crop production and physiology at Iowa State University, whose "scientific research focuses on understanding environmental factors that affect pollination and seed formation" (Westgate, 2010, p. 1). Hoffman is a plant physiologist who is currently an APHIS official. Among his previous positions were professor of plant biology at the Carnegie Institution and Stanford University (Hoffman 2010a, p. 1). Panella, a plant geneticist, is research leader of the sugar beet research unit at the USDA ARS Crop Research Laboratory in Fort Collins, Colorado (Panella, 2010, p. 1).

Westgate explains that most pollen falls within the "immediately surrounding" area of the source field. In addition, many other factors affect the possibility of cross pollination in two *Beta* seed production fields, including receptiveness of the female, wind and humidity conditions, viability of the pollen, and competition (see Section 2.4 for a general discussion of these factors). For example, Swiss chard and table beets that are grown for seed are primarily open pollinated (all plants produce pollen) rather than hybrids using male sterile females, as is used in the production of most sugar beet seed (discussed in Section 2.7). The pollen cloud in an open

pollinated field is "typically four times more dense than the local pollen cloud for a standard hybrid field" with "billions" of pollen grains per square meter making it much more difficult for a small amount of the stray pollen that might be carried on the wind from another field to compete in the open pollinated fields (Westgate, p. . 5). Westgate concludes, in general, "when all the principal factors affecting pollination are considered, the probability of pollination of table beet or chard fields by sugar beet pollen in the Willamette Valley is infinitesimally small" (Westgate, 2010, p. 6).

Hoffman indicates that nearly all fertilization from a pollen source (99.9%) occurs within the first 500 m (about 0.3 miles), and that any pollen that might reach another downwind field would have to compete with pollen from that field. Based on his assessment of conditions in the Willamette Valley, Hoffman concluded that the 4-mile isolation distance (as articulated in Interim measure No. 2) "to isolate unlike sexually compatible crops such as Swiss chard, table beets and sugar beets is more than 12 times the distance needed to reduce cross-pollination between RRSB and Swiss chard to 0.1% (1 seed in 1000) in a worst case scenario without competition from a local pollen source" (Hoffman, 2010a, p. 14). Hoffman expects the level of gene flow to be less than one seed in 10,000 (0.01%) with a four mile isolation distance. Panella concurred with Hoffman's analysis and conclusion (Panella, 2010, p. 5). Carol Mallory-Smith, PhD, professor in the Department of Agriculture at Oregon State University in the Willamette Valley, concluded that the "proposed restrictions [interim measure including a 4 mile isolation distance] will provide significant safeguards to protect Beta species seed producers while the EIS is being conducted" and that the risk of geneflow would be "extremely low." (Mallory-Smith, 2010, pp. 1-2).

3.9.7 Use of event H7-1 trait on male-sterile female

Seed production companies use a hybrid seed production system in which the event H7-1 trait is on the female (male sterile plants) in a large proportion of commercial seed production fields. In the Willamette Valley at least two seed companies use this system exclusively (Anfinrud, 2010, pp. 1-2; Lehner, 2010, pp. 5-6; Meier, 2010, p. 8). Essentially zero event H7-1 pollen is produced by these "female side" seed production fields. As a result of these methods, 78.6% of the currently growing GE sugar beet seed crop in the Willamette Valley is male-sterile female. Because these plants produce virtually zero pollen, they eliminate any realistic risk for unintentional spread of the GE trait.

3.9.8 Red table beet offtypes

Seed companies growing sugar beets in the Willamette Valley occasionally find a very small percentage of off-types from red table beet crops. Seed companies have indicated a very low level of off-types in sugar beet crops, and one seed company reports that its latest "observation plots did not produce any off-types" (Lehner, 2010, p. 3). Customers (i.e., growers of commercial sugar beet root crops) have likewise indicated that after inspecting the millions of plants grown in variety trials conducted over several years, "the number of chard or red beet off-types were so small as to be, for all intents and purposes, not quantifiable." (Grant, 2010, p.6; Berg, 2010, p. 5; Hofer, 2010, p.4). Seed companies regularly perform grow out tests to determine if there are any issues with off-types (Lehner, 2010, p.3; Hovland, 2010, pp. 2-3). Red table beet offtypes in sugar beet fields could occur due to nearby backyard gardeners growing red table beets, or might occur from open pollinated red table beet fields upwind from sugar beet fields. (Anfinrud, 2010, 109:13-17). In an open pollinated field, every plant sheds pollen (Stander, 2010, p. 2). Thus an acre of open pollinated red table beets would produce far more pollen than an acre of hybrid sugar beet fields, where the only one-fourth to one-third of the plants produce pollen (Westgate, 2010, p. 5). The Willamette Valley Specialty Seed Association pinning guidelines and isolation distances require 4 mile isolation distances between open pollinated red beet and sugar beet fields, in order to limit red beet off types in sugar beet fields (Stander, 2010, p. 2). The potential for sugar beet gene transmission to open pollinated red beet fields is very low, because as indicated, a greater volume of pollen per acre are shed by the open pollinated field (Westgate, 2010, p. 5) (indicating "billions" of pollen grains per square meter shed by an open pollinated red beet field).).

3.9.9 No sensitivity to event H7-1 by conventional sugar beet growers; Stewardship regarding mechanical mixing

There is no indication of sensitivity by customers for conventional sugar beet seed to the possibility of an inadvertent presence of event H7-1 genetic material in the conventional seed (Pierson, 2010, p. 17). First, there is currently no market in the U.S. for organic sugar beets (Pierson, 2010, p. 17). Second, in most areas where both event H7-1 and conventional sugar beets are grown, both types of beets would be combined and processed together, with no effort to differentiate between sugar from H7-1 and conventional beets (Pierson, 2010, pp. 16-17). The sugar from conventional beets does not differ chemically or in any other way from the sugar from H7-1 beets (Hoffman, 2010, p. 16).

As set forth in Section 2.7.3, each of the seed companies producing H7-1 seed utilizes detailed measures to address the possibility of mechanical mixing of H7-1 and conventional sugar beet

seed. These measures would be subject to audit under the interim measures to ensure that they continue to be utilized and are successful.

Because seed production for red beet and chard seed crops is completely separate from sugar beet seed production, there is virtually no risk of mechanical mixing. As discussed in Section 2.8, the two types of production employ different growers, different equipment and different facilties. Accordingly, there is no significant risk of mixing.

3.9.10 Question of zero tolerance

We have identified one organic seed producer who has chosen to produce organic chard seed (among several other organic crops) in the Willamette Valley. This organic producer has approximately one to three acres of production on the Western margin of the Valley. He has indicated that he faces a risk of genetic transfer from event H7-1 seed fields, and that he sells to customers for his organic chard with **zero tolerance** for any level of outcrossing with event H7-1. That producer has tested his chard seeds since 2007 with a PCR genetic test and found no indications of event H7-1 traits in his crops. To date, he has not lost sales due to a risk of cross pollination from Event H7-1. He reports that the costs of the PCR testing for multiple years since 2007 have totaled roughly $700, and that a positive test for event H7-1 for his crop could negatively affect the reputation that producer has with his customers. That seed producer has also indicated in public statements through the media that he is not concerned about a risk of cross-pollination from event H7-1 seed fields where the GE trait is on the female non-pollinator (Morton, 2009, 9:12-19). A seed retailer who buys from that producer has reported that he has multiple sources for chard seed outside the Willamette Valley, including in California, but continues to purchase from that producer nevertheless.

In addition, both that seed producer and the seed retailer have participated in the development of a consensus standard setting a threshold for the presence of GE traits in organic food products and in seed. The Non-GMO Project Working Standard, sponsored by leading players in the organic industry (including Whole Foods), specifically permits crops to be verified "non-GMO" despite the presence of a low level of biotech content—0.25% for GE sugar beet seed and other *Beta* seed crops (Non-GMO Project, 2010, pp. 25, 34) and 0.9% in organic food and feed. Section 2.4.3 of the Working Standard explains that its product content standards apply to the crops listed on Appendix B, plus "close relatives of these crops that are subject to cross pollination" (Non-GMO Project, 2010, p. 12). Appendix B specifically lists "sugar beets" as one of those crops "with GMO Risk" subject to the standard, and also expressly identifies "chard"

and "table beets" as close relatives for which cross-pollination is possible (Non-GMO Project, 2010, p. 34). Section 2.6 explains that "[t]he Non-GMO Project has established" a 0.1% GMO content threshold for "seed and other propagation materials" for all crops listed in Appendix B, but the standards include a specific variance of 0.25% for sugar beet seeds and other crops identified (Non-GMO Project, 2010, pp. 14, 34). This 0.25% level is thus the Working Standard's current threshold for "non-GMO" sugar beet seed and other *Beta* seed crops.

Other commercial producers of sugar beet, red beet or chard seed in the Willamette Valley have all consented to and abide by the Willamette Valley Specialty Seed Association standards, discussed in Section 2.7 and Appendix A.

3.9.11 Seed availability

As discussed in Section 2.7, sugar beet variety development is competitive, technological, and expensive multi-year activity. Seed companies develop varieties with traits they expect growers to want, and the sugar beet companies seed selection committees chose the varieties they wish to grow. It is a market-driven process, where the grower cooperatives themselves determine what is available for planting. Every year, each sugar beet company has a number of varieties that growers may choose from. As the popularity of event H7-1 sugar beet among growers has grown, there have been fewer available conventional varieties and more event H7-1 varieties; however, conventional varieties have been available. There is no organic sugar beet seed production in the sugar beet seed production areas.

Conventional and/or organic sugar beet seeds are available from some US seed suppliers (conventional), and from European seed companies (conventional and organic). (SESVaderHave, 2010; Millington Seed Company, 2010). KWS has some 250 varieties of sugar beet seeds available, including organic (KWS, Grain, 2008). Organic sugar beet is a noteworthy crop in the EU (Eurostat, 2010). Not all organic beets are processed into sugar; some are used to produce a syrup that is integrated into organic food preparations (Ceddia and Cerezo, 2008).

3.9.12 Impact Summary

Alternative 1

Under Alternative 1, there would be no gene flow impacts to growers of organic or conventional *Beta* seed from the production of event H7-1 sugar beet seed.

Alternative 2

Under Alternative 2, no or negligible impacts from event H7-1 seed production on growers of organic or conventional *Beta* seed are expected for the following reasons:

- The large majority of red beet and chard seed crops are grown in different geographic areas than are Event H7-1 sugarbeets.
- Even in the Willamette Valley (where most sugarbeet seed crops and a limited acreage of other beta species seed crops are grown), there have been no reported impacts since H7-1 commercial seed production began in 2006, and with the proposed interim measures, the potential for impacts would be further reduced.
- Based on 1) the use in the majority of the event H7-1 seed production of the trait on the male-sterile female; 2) results of sugar beet pollination outcrossing data in the published scientific literature; 3) site-specific modeling; 4) the relationship between expected seed purity levels and isolation distances determined by the OSCS; 5) the results of experience and testing in the Willamette Valley seed production area since 2007 and, 6) the analysis and conclusions of qualified scientists who specifically addressed this issue, the 4-mile isolation distance (Interim measure Item 2) is expected to result in eliminating any significant risk that cross-pollination of organic or conventional red beet or chard crops will occur, and if it happens, make the rate of outcrossing very low if not undetectable – likely at rates of less than 1 in 10,000 (less than one seed in 10,000 with the event H7-1 trait). This is, for example, far less than the non-GMO Project proposed tolerance levels for sugar beet and other *Beta* seed (0.25%) (Non-GMO Project, 2010),
- The use of hybrids with the event H7-1 trait on the female, in combination with the disclosure requirements regarding male fertile event H7-1 seed crops (Interim measure Item 3) will drastically reduce the potential for cross-pollination. For the large majority of H7-1 seed fields (with the trait on the female), there is essentially zero risk of crossing with a red beet or chard seed crop. For those fields with the H7-1 gene on the male pollinator, the isolation distances will reduce any risk significantly, and producers of red beet and chard can ascertain what those distances are and take appropriate measures (to position their fields, scout for off-types, conduct genetic testing, or through other means discussed herein) if they are concerned about any level of risk.
- The interim measure to prevent seed mixing (Interim measure Item 4), which makes current seed and steckling production and handling practices mandatory (described in Section 2), will make the potentially low level presence of event H7-1 in conventional sugar beet seed negligible and will eliminate adventitious presence of event H7-1 in other *Beta* seeds.

Conventional sugar beet seed will continue to be available as long as growers continue to choose it in the variety trials. Growers who purchase seed purchase a specific variety, which is labeled as such.

In addition, in the event unwanted transmission of H7-1 traits to a red beet or chard crop did occur, there are multiple means for a seed producer to address it. First, because a seed producer of red beet or chard growing beta species typically will inspect each plant remove any off-types from his production fields, any preexisting unwanted cross between a sugar beet and red beet or chard plant can be addressed before seed is produced with an unwanted trait

(Stander, 2010, pp. 3 - 4). Second, once seed is produced, a grower typically will perform grow-out tests on a sample of the seed to confirm that the seed is producing plants without undesired off-types. This can also identify any issues. Third, multiple types of genetic testing can be conducted to confirm the lack of any H7-1 trait (Hovland, 2010, pp. 2 - 3). While PCR testing is available with a very high level of sensitivity (to 0.01%), inexpensive genetic strip tests capable of identifying H7-1 are also available for $2 to $4 per test, with a sensitivity of approximately 0.1% (Stander, 2010, pp. 4 - 5). Such testing may be utilized in a manner that employs samples from multiple seed plants and reduces the number of tests required per field. In the event of a positive test, the seed producer may use additional testing to isolate the source of the portion of his field producing that result (*Id).* Further, retailers of seed with sensitivity to H7-1 content may also conduct grow out tests, or utilize the same genetic testing methods to address any concerns they may have (*Id*)

As discussed in Section 3.17, in light of the above factors, the socioeconomic impacts on farmers growing red table beet and Swiss chard seed are negligible.

3.10 LIVESTOCK PRODUCTION SYSTEMS

The only impacts to livestock production systems would be related to animal feed, which is discussed in Section 3.11.

3.11 FOOD AND FEED

Both food (sugar and molasses derivatives) and animal feed (molasses and beet pulp) are derived from sugar beets. In this section we summarize the large body of scientific evidence that has been developed that supports the conclusion that food and feed derived from event H7-1 sugar beets are as safe and healthy as food and feed derived from conventional sugar beets. While the evidence has largely been developed by Monsanto and/or KWS and the contract research organizations supported by Monsanto and/or KWS, it has been evaluated and peer reviewed by panels of government scientists from the US, Canada, the European Union (EU), Japan, Australia, New Zealand, Mexico, South Korea, the Russian Federation, China, Singapore, Colombia and the Philippines, all of whom have approved, or recommended for approval, the use of products from event H7-1 in their countries (FSANZ, 2005; Monsanto/KWS 2007; Berg 2010).

We begin with a summary of FDA's authority and policy under the federal Food, Drug and Cosmetic Act (FFDCA) with regard to ensuring the safety of food and feed derived from new plant varieties developed using rDNA methods. We then document each element FDA

evaluated in its consultation process. Then we summarize the evaluations and conclusions of several other international scientific oversight groups.

3.11.1 FDA authority and policy

FDA policy statement. In 1992, the FDA issued a policy statement clarifying its interpretation of the FFDCA, regarding foods (including animal feed) derived from new plant varieties, including plants developed by the newer methods of genetic modification, including rDNA. The purpose of the policy is "to ensure that relevant scientific, safety, and regulatory issues are resolved prior to the introduction of such products into the marketplace" (FDA, 1992). FDA is the "primary federal agency responsible for ensuring the safety of commercial food and food additives, except meat and poultry products" and "FDA has ample authority under the act's [FFDCA] safety provisions to regulate and ensure the safety of foods derived from new plant varieties, including plants developed by new techniques. This includes authority to require, where necessary, a premarket safety review by FDA prior to marketing of the food" (FDA, 1992). Under section 402(a)(1) of the FFDCA, a food is adulterated and thus unlawful "if it bears or contains an added poisonous or deleterious substance that may render the food injurious to health or a naturally occurring substance that is ordinarily injurious" (FDA, 1992).

FDA has the authority to ensure safety of new foods. FDA considers its existing statutory authority under the FFDCA and its implementing regulations "to be fully adequate to ensure the safety of new food ingredients and foods derived from new varieties of plants, regardless of the process by which such foods and ingredients are produced" (FDA, 1992). "The existing tools provide this assurance because they impose a clear legal duty on producers to assure the safety of foods they offer to consumers; this legal duty is backed up by strong enforcement powers; and FDA has authority to require premarket review and approval in cases where such review is required to protect public health" (FDA, 1992).

Developers have the responsibility to evaluate the safety of new foods. "It is the responsibility of the producer of a new food to evaluate the safety of the food and assure that the safety requirement of section 402(a)(1) of the act is met. FDA provides guidance to the industry regarding prudent, scientific approaches to evaluating the safety of foods derived from new plant varieties, including the safety of the added substances that are subject to section 402(a)(1) of the act. FDA encourages informal consultation between producers and FDA scientists to ensure that safety concerns are resolved" (FDA, 1992).

Foods developed by new methods do not present greater safety concerns. "FDA believes that the new techniques are extensions at the molecular level of traditional methods and will be used to achieve the same goals as pursued with traditional plant breeding. The agency is not aware of any information showing that foods derived by these new methods differ from other foods in any meaningful or uniform way, or that, as a class, foods developed by the new techniques present any different or greater safety concern than foods developed by traditional plant breeding" (FDA, 1992).

FDA's goal is to ensure the safety of all food and feed. "The goal of the FDA's evaluation of information on new plant varieties provided by developers during the consultation process is to ensure that human food and animal feed safety issues or other regulatory issues (e.g. labeling) are resolved prior to commercial distribution" (FDA, 1997).

3.11.2 FDA biotechnology consultation note to the file BNF 000090

FDA makes the contents of its biotechnology notification files (BNFs) available on the internet (see reference FDA, 2004; event H7-1 is BNF 000090)[35]. FDA documented its consultation with Monsanto/KWS on event H7-1 in a note to the file dated August 7, 2004 (Bonette, 2004). That information is summarized below.

Characterization, inheritance, and stability of the introduced DNA

Using standard analytical techniques, Monsanto/KWS verified that event H7-1 contained a single copy of the EPSPS cassette, and that all components were intact (Bonnette, 2004; Schneider, 2003, p. 43).

Monsanto/KWS conducted crosses using conventional breeding techniques resulting in 27 breeding experiments over four generations. These studies indicate that the introduced trait (glyphosate tolerance) was stably inherited as a dominant trait (Bonette, 2004; Schneider, 2003, p. 44).

Using standard analytical techniques, Monsanto/KWS demonstrated the stable integration of the T-DNA over three generations (Bonette, 2004; Schneider, 2003, p. 47).

Introduced substance – CP4 EPSPS enzyme

As discussed in Section 3.1.1, EPSPS is a catalyst for a reaction necessary for the production of certain aromatic amino acids essential for plant growth and has a similar function in bacteria

[35] http://www.accessdata.fda.gov/scripts/fcn/fcnDetailNavigation.cfm?rpt=bioListing&id=19

and fungi (for example, baker's yeast). While EPSPS is present in plants, bacteria and fungi, it is not present in animals; animals do not make their own aromatic amino acids, but rather obtain them from the foods they consume. Thus, EPSPS is normally present in food and feeds derived from plant and microbial sources (Harrison et al, 1996). There are variations in the genetic makeup (amino acid sequences) of EPSPS among different plants and bacteria. The EPSPS from *Agrobacterium* sp. strain CP4 is just one variant of EPSPS. A unique characteristic of the CP4 EPSPS is that, unlike EPSPS enzymes commonly found in plants, it retains its catalytic activity in the presence of glyphosate (Bonnette, 2004; Schneider, 2003, pp 50-51; Padgette et al, 1995).

Concentrations in sugar beet. In 1999, field trials were conducted at six distinct field locations distributed across Europe in the major sugar beet production areas. The event H7-1 sugar beets were treated with a Roundup agricultural herbicide. Samples of brei (root tissue processed using standard sugar beet industry methods) and top (leaf) tissues were collected and analyzed for levels of the CP4 EPSPS protein. On average, concentrations of the CP4 EPSPS protein, on a fresh weight basis, were similar in the leaf tissue (161 µg/g) and in the root tissue (181 µg/g). The range of mean levels of the CP4 EPSPS protein in top (leaf) tissue was 112 to 201 µg/g and in root (brei) were 145 to 202 µg/g across the sites (Schneider, 2003).

Toxicity of CP4 EPSPS. Studies were conducted on mice, using CP4 EPSPS doses of 400, 100 and 40 milligrams (mg) of CP4 EPSPS per kilogram of body weight per day (mg/kg body wt –d). For a typical 0.03-kg mouse, the 400 mg/kg body wt/d dose equated to 12 mg CP4 EPSPS per mouse per day. The study was designed to reflect a 1,000-fold factor of safety on the highest possible human exposure to CP4-EPSPS, based on assumed exposures to soybean, potato, tomato and corn at the time the study was done (Harrison et al, 1996)[36]. The daily CP4 EPSPS content in the maximum mouse exposure was equivalent to the amount in approximately 160 pounds of H7-1 sugar beets. No treatment-related adverse effects were observed, and there were no significant difference in any measured endpoints between the CP4 EPSPS treated mice and the control group (Harrison, et al, 1996, p. 735).

Monsanto/KWS also compared the amino acid sequence of CP4 EPSPS to protein sequences in the public domain ALLPEPTIDES database using the FASTA algorithm, and reported no biologically relevant sequence similarities between CP4 EPSPS protein and known protein

[36] Note that this was a theoretical exercise as no glyphosate tolerant potatoes or tomatoes are commercially grown.

toxins were observed (Bonnette, 2004). A peptide is a molecule consisting of several linked amino acids (GMO Safety, 2010a).

Allergenicity. Allergens can be derived from many sources: in animal hair, pollen, insect bites, dust mites, plants, pharmaceuticals, and food. Approximately 20,000 allergens have been identified. Most allergens in food are high molecular weight proteins and are rather resistant to gastric acid and digestive enzymes (GMO Safety, 2010a).

Monsanto/KWS searched a comprehensive database of allergens (Hileman et al, 2002) containing sequences of known allergens, for amino acid homology to the CP4-EPSPS protein, and concluded that there was no immunologically significant amino acid sequence homology between the CP4 EPSPS protein and amino acid sequences of allergens in the database (Bonnette, 2004).

Monsanto/KWS discussed two studies relevant to the mammalian digestibility of CP4 EPSPS. In the first study, the CP4 EPSPS protein was exposed to simulated gastric (stomach) and intestinal fluids that were prepared according to the US Pharmacopoeia (1990). The half-life of the CP4 EPSPS protein was reported to be less than 15 seconds in the gastric fluid, greatly minimizing any potential for the protein to be absorbed in the intestine. The half-life was less than ten minutes in the simulated intestinal fluid (Harrison et al, 1996, p 738). The second study reported similar results (Bonnette, 2004).

Food and feed uses of sugar beet

The main food use of sugar beet is for the extraction of sucrose from sugar beet roots through a process involving hot water extraction, followed by purification, evaporation, and centrifuge separation of sucrose crystals (granular sugar). Refined sucrose does not contain protein or other genetic material. This process also yields sugar beet molasses and sugar beet pulp, which are often pelleted and used in animal feed. The leafy sugar beet "tops" are usually left in the field, but they may occasionally be fed to ruminant animals (Bonnette, 2004).

Compositional analysis

To assess whether sugar beet event H7-1 is as safe and nutritious as conventional sugar beet varieties, Monsanto/KWS compared the composition of the hybrid lines containing event H7-1, produced through conventional breeding, to the composition of the corresponding non-transgenic, control. Tops (leaves) and brei (processed roots) were analyzed using standard methods or other suitable methods (Bonnette, 2004).

These analyses included proximate values (crude ash, crude fiber, crude fat, crude protein and dry matter), carbohydrates, quality parameters, saponins (naturally-occurring antinutrients that have a bitter taste and can act as a deterrent to foraging), and eighteen amino acids. Quality parameters measured in root samples included percent sucrose, invert sugar, sodium, potassium and alpha-amino nitrogen. All analyses were conducted as a single analysis for the root (brei) and top (leaf) samples collected as three replica samples from each of five field trials sited. Fifty-five statistical comparisons were made with the control line, of which seven were found to be statistically different ($p<0.05$). Based on the statistical methods, three of these seven would have been expected based on chance. In all seven cases, the ranges for the statistically different components in event H7-1 significantly overlapped or fell completely within the range of values observed for the control, the conventional reference varieties and for available published values from conventional sugar beet varieties (Schneider, 2003, Section C).

Conclusion

Based on the data submitted, the FDA considered the consultation process to be complete, and acknowledged this in a note to the file and a letter to Monsanto (Bonnette, 2004; Tarantino, 2004).

3.11.3 Health Canada approval 2005

Health Canada's Food Directorate has legislated responsibility for premarket assessment of "novel foods." Under Canadian regulations, sugar derived from event H7-1 sugar beet is a novel food because it is derived from a plant that has been genetically modified to exhibit characteristics that were not previously observed in the plant (Health Canada, 2005).

Health Canada "conducted a comprehensive assessment of this sugar beet according to its *Guidelines for the Safety Assessment of Novel Foods*," reviewing the same information Monsanto/KWS provided to FDA in its consultation, and made the following conclusion (Health Canada, 2005:

> Health Canada's review of the information presented in support of the food use of sugar from glyphosate tolerant sugar beet lines containing event H7-1 concluded that the food use of sugar from sugar beet lines containing this event does not raise concerns related to safety. Health Canada is of the opinion that sugar from sugar beet lines containing event H7-1is as safe and nutritious as sugar from current commercial sugar beet varieties.

3.11.4 Canadian Food Inspection Agency (CFIA) approval 2005

The CFIA evaluated event H7-1 both as a crop to be potentially grown in Canada, and as livestock feed, and approved both uses in 2005. Based its evaluation of data provided by Monsanto/KWS, and as summarized in its Decision Document DD2005-54, the CFIA "determined that this plant with a novel trait (PNT) and novel feed does not present altered environmental risk nor does it present livestock feed safety concerns when compared to currently commercialized sugar beet varieties in Canada" (CFIA, 2005).

3.11.5 EFSA risk assessment and EC authorization

The European Food Safety Authority (EFSA) is an independent European agency funded by the EU budget for the purpose of assessing risks associated with the food chain. Risk assessment is a specialized field of applied science that involves reviewing scientific data and studies to evaluate risks associated with certain hazards (EFSA 2010). EFSA conducts risk assessment, but does not have authority to authorize use. The European Commission (EC), which is the executive body of the EU, determines whether or not a genetically modified item will be authorized for use in the EU.

Scope and process. The scope of the Monsanto/KWS application to the EFSA was for food and feed, and not as a crop intended for cultivation in the EU (EFSA, 2006, p. 1). The EFSA used the same data Monsanto/KWS provided to the FDA, Health Canada, and the CFIA, and also requested additional information. The Scientific Panel on Genetically Modified Organisms (GMO Panel) developed an opinion that was then adopted by the EFSA. Subsequently, in 2007, the EC authorized "the placing on the market of food and feed produced from genetically modified sugar beet H7-1" (EC, 2007). During the EFSA risk assessment process, Member states comment on the draft decisions and can request further analysis; the GMO Panel also can request additional information from the applicant.

Detectable presence of CP4 EPSPS. The GMO Panel reported that if the CP4 EPSPS protein was present in the sugar, which was unlikely, it was below the detection limit of 0.004 parts per million (ppm). No DNA was detected in the sugar and the molasses is also "free from DNA and protein (limit of detection 0.002 ppm)." The CP4 EPSPS protein is present in pulp at levels around 500 ppm on a dry weight basis (EFSA, 2006, p. 9).

Safety of the CP4 EPSPS protein. The GMO Panel noted the "long history of dietary exposure to EPSPS proteins" for humans and animals the fact that "previous applications for glyphosate tolerant crops containing the CP4 EPSPS protein have been evaluated and found to be safe for human and/or animal consumption in previous [EFSA] opinions." The GMO Panel concluded that "a toxicological assessment of new constituents is not applicable" (EFSA, 2006, p 10).

Additional toxicity study. In response to EFSA information requests, Monsanto/KWs conducted a 90-day toxicity study, feeding processed pulp to rats, which did not indicate any adverse effects. The GMO Panel reported additional studies of sugar beet pulp to sheep, also with no adverse effects (EFSA, 2006)[37].

Allergenicity. In addition to evaluating the potential allergenicity of the CP4 EPSPS protein, the GMO Panel considered whether the insertion of the transgene could result in modifications of the pattern of expression of other potentially allergenic proteins within the sugar beet plant. The Panel did not consider the issue to be relevant, as sugar beet is not a major allergenic food, and overexpression of an existing protein "would be unlikely to alter the overall allergenicity of the whole plant (EFSA, 2006, p. 12).[38]

No need for post-market monitoring. The GMO Panel noted "No risks to human and animal health were identified in studies of the CP4 EPSPS protein expressed in sugar beet H7-1, and in studies of the genetically modified sugar beet itself. Thus, foods and feeds produced from sugar beet H7-1 is as safe and nutritious as foods and feeds derived from conventional sugar beets." The Panel recommended no post-market monitoring (EFSA, 2006, p. 13).

Conclusions. The GMO Panel stated the following in its conclusions (EFSA, 2006, p. 13):

- Sugar and molasses have been shown to be free from DNA and protein
- Animals fed with pulp will be exposed to the CP4 EPSPS protein
- The CP4 EPSPS protein has been evaluated and found to be safe for human and/or animal consumption
- The molecular characterization and the comparative compositional analysis did not indicate the occurrence of any unintended effects due to the genetic modification
- Products from sugar beet H7-1 are safe as food and feed
- The nutritional value of the sugar beet H7-1 and the derived sugar beet products is comparable to that of the analogous products from conventional sugar beet
- The risk of allergenicity is of no concern with this product

3.11.6 Other approvals

Japan approved the use of event H7-1 in feed 2003, in food in 2005, and the environmental in 2007 (Sato, 2008). Studies by the Japanese National Food Research Institute have confirmed that there is no detectable DNA in sugar from sugar beets, with the conclusions that "sugar beet

[37] http://jas.fass.org/cgi/content/full/83/2/400
[38] http://jas.fass.org/cgi/content/full/83/2/400

DNA was degraded at an early stage of sugar processing" (Oguchi et al, 2009). Event H7-1 has also been approved for food and feed use in Mexico, South Korea, Australia, New Zealand, China, Colombia, the Russian Federation, Singapore and the Philippines (FSANZ, 2005; Monsanto/KWS 2007; Berg 2010).

3.11.7 Willingness of the buyer to accept sugar from event H7-1

Market concerns about willingness of buyers to accept sugar, molasses, and/or pulp derived from event H7-1 have not resulted in any perceptible change in the demand for US-produced beet sugar or other fractions. Based on the regulatory approvals obtained in domestic and international markets, sugar, molasses, and pulp derived from event H7-1 is being successfully marketed.

As summarized above, there is a large body of scientific evidence that has been reviewed and validated by several international scientific panels that supports the safety of the sugar and other fractions derived from event H7-1 for food and feed use. If there are consumers who do not wish to purchase sugar made from event H7-1 for reasons other than safety and health, they have the option of buying sugar made from sugarcane, which is not currently produced using lines that were developed using modern biotechnology. However, the majority of food products containing beet sugar, such as cakes, candy, ice cream and other sweets, are likely to contain sugar derived from sugar beet varieties containing event H7-1. Most commercial food and beverage products are also likely to contain corn or soy products derived from biotech crops (Goldsbrough, 2000).

3.11.8 Impacts

Based on the scientific evidence summarized in this section, impacts on food and feed are not expected with either alternative. Food and feed derived from event H7-1 is equivalent to food and feed derived from conventional sugar beets. Because both conventional and event H7-1 sugar beets are processed in the same facilities, there is no distinction in the US between food and feed derived from conventional and event H7-1 sugar beets. Markets are available for all the food and feed produced. Because there is no commercial organic sugar beet industry in the US, organic sugar beet production is not impacted in any way.

Aside from sugar, the other products from sugar beets (molasses and pulp) are not major consumer items and can easily be avoided by consumers who do not wish to be exposed to GE products. As discussed above, there is no detectable DNA in processed sugar; however, consumers who wish to avoid all products derived from GE crops can purchase cane sugar rather than beet sugar. While processed foods, the situation is similar to that for corn and soy

products: even without event H7-1, it would be very difficult for a consumer to avoid products derived from GE crops.

3.12 WEED CONTROL AND GLYPHOSATE RESISTANCE

As indicted in Section 1, EPA is responsible for regulation of glyphosate and thus for issues of weed resistance to glyphosate (EPA, 2003).. This report nevertheless analyzes those issues. APHIS's 2005 EA did so as well, and the court did not find a deficiency in that analysis. APHIS has performed other herbicide resistance analyses in many E As conducted as part of the petition review process (see http://www.aphis.usda.gov/biotechnology/not_reg.html).

3.12.1 Herbicide-resistant weeds

As explained in Section 2.5, not all weed species respond the same to every herbicide mode of action. Instead, a weed species can have a natural resistance to a particular mode of action, and if a grower employs only that mode of action, over time, the naturally resistant species will overtake other weed species in that area. This is often referred to as a shift in the weed population. It is for this reason that growers may need to use multiple products to control the full spectrum of weeds in a field.

Sugar beet weed management, including major weeds in sugar beets, herbicides used, herbicide mode of action and herbicide resistance, was discussed in Section 2.4. Table 3-1 summarizes the major sugar beet weeds in terms of resistance to herbicide groups used in sugar beets for the states where sugar beets are grown commercially. A weed is listed for a state when herbicide resistance has been confirmed. The table does not show the extent of the weeds with the noted resistance; this would vary widely. References for the table are included at the bottom of the table.

As of June 27, 2010, 194 herbicide-resistant weed species (341 herbicide resistant weed biotypes) have been documented worldwide (Heap, 2010). These species have been reported to be resistant to 19 different herbicide modes of action (Heap, 2010). Approximately five

Table 3-1 Major sugar beet weeds with resistance to herbicides groups used in sugar beets[1]

California

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Echinochloa crus-galli*	Barnyardgrass	2000	ACCase inhibitor
2. *Echinochloa crus-galli*	Barnyardgrass	2000	fatty acid synthesis inhibitor.

Colorado

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Aramanthus retroflexus*	Redroot pigweed	1982	photosystems II inhibitors
2. *Kochia scoparia*	Kochia	1982	photosystems II inhibitors
3. *Kochia scoparia*	Kochia	1989	ALS inhibitors
4. *Avena fatua*	Wild Oat	1997	ACCase inhibitors

Idaho

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Kochia scoparia*	Kochia	1989	ALS inhibitors
2. *Avena fatua*	Wild Oat	1992	ACCase inhibitors
3. *Avena fatua*	Wild Oat	1993	fatty acid synthesis inhibitor.
4. *Kochia scoparia*	Kochia	1997	synthetic auxins
5. *Aramantus retroflexus*	Redroot pigweed	2005	photosystems II inhibitors

Michigan

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Chenopodium album*	Lambsquarters	1975	photosystems II inhibitors.
2. *Amaranthus tuberculatus*	Tall waterhemp	2000	ALS inhibitors
3. *Amaranthus powellis*	Powell Amaranth	2001	photosystem II inhibitors
4. *Amaranthus powellis*	Powell Amaranth	2001	ureas and amides
5. *Amaranthus retroflexus*	Redroot Pigweed	2001	photosystems II inhibitors.
6. *Chenopodium album*	Lambsquarters	2001	ALS inhibitors
7. *Amaranthus hybridus*	Smooth Pigweed	2002	ALS inhibitors
8. *Abutilon theophrasti*	Velvetleaf	2004	photosystems II inhibitors
9. *Solanum ptycanthum*	East. Black nightshade	2004	photosystems II inhibitors
10. *Solanum ptycanthum*	East. Black nightshade	2004	photosystems II inhibitors.
11. *Kochia scoparia*	Kochia	2005	ALS inhibitors
12. *Setaria faberi*	Giant Foxtail	2006	ALS inhibitors

Minnesota

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Chenopodium album*	Lambsquarters	1982	photosystems II inhibitors. (PI)
2. Abutilon *theophrasti*	Velvetleaf	1991	PI
3. *Amaranthus retroflexus*	Redroot Pigweed	1991	PI
4. *Avena fatua*	Wild Oat	1991	ACCase inhibitors
5. Amaranthus tuburculatus	Tall Waterhemp	2007	glycine, ALS, PI
6. Ambrosia trifida	Giant ragweed	2006	glycine, ALS inhibitors, PI
7. *Kochia scoparia*	Kochia	1994	ALS inhibitors
8. *Xanthium strumarium*	Common cocklebur	1994	ALS inhibitors
7. *Setaria faberi*	Giant Foxtail	1996	ALS inhibitors
9. *Setaria viridis*	Robust White Foxtail (var. robusta-alba Schreiber)	1996	ALS inhibitors
10. *Setaria lutescens*	Yellow Foxtail	1997	ALS inhibitors
11. *Ambrosia trifida*	Giant ragweed	2006	glycines
12. *Amaranthus tuberculatus*	Tall waterhemp	2007	glycines

Montana

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Kochia scoparia*	Kochia	1984	photosystems II inhibitors
2. *Kochia scoparia*	Kochia	1989	ALS inhibitors
3. *Avena fatua*	Wild Oat	1990	fatty acid synthesis inhibitor.
4. *Avena fatua*	Wild Oat	1990	ACCase inhibitors
5. *Kochia scoparia*	Kochia	1995	synthetic auxins
6. *Avena fatua*	Wild Oat	1996	ALS inhibitors
7. *Avena fatua*	Wild Oat	2002	ACCase inhibitors

Nebraska

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Amaranthus tuberculatus*	Tall waterhemp	1996	photosystem II inhibitors

North Dakota

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Kochia scoparia*	Kochia	1987	ALS inhibitors
2. *Setaria viridis*	Green Foxtail	1989	mitois inhibitors
3. *Avena fatua*	Wild Oat	1991	ACCase inhibitors
4. *Kochia scoparia*	Kochia	1995	synthetic auxins
5. *Avena fatua*	Wild Oat	1996	ALS inhibitors
6. *Kochia scoparia*	Kochia	1998	photosystems II inhibitors
7. *Amaranthus retroflexus*	Redroot Pigweed	1999	ALS inhibitors
8. *Solanum ptycanthum*	Eastern Blk.Nightshade	1999	ALS inhibitors

Oregon

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Avena fatua*	Wild Oat	1190	ACCase inhibitors
2. *Avena fatua*	Wild Oat	1990	mitosis inhibitors
3. *Kochia scoparia*	Kochia	1993	ALS inhibitors
4. *Amaranthus retroflexus*	Redroot Pigweed	1994	photosystems II inhibitors.

Washington

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Kochia scoparia*	Kochia	1989	ALS inhibitors
2. *Avena fatua*	Wild Oat	1991	ACCase inhibitors
3. *Amaranthus powellis*	Powell Amaranth	1992	photosystem II inhibitors
4. *Sonchus asper*	Spiny Sowthistle	2000	ALS inhibitors

Wyoming

Species	Common Name	Year[2]	Herbicide Mode of Action
1. *Kochia scoparia*	Kochia	1984	photosystems II inhibitors
2. *Kochia scoparia*	Kochia	1996	ALS inhibitors

Legend:

[1] *Source: Heap, I. The International Survey of Herbicide-resistant Weeds. Online. Internet. Accessed on June 21, 2010 at: www.weedscience.com.*

[2] *Year resistance was first reported.*

percent of resistant species have resistance to EPSPS inhibitors (glycines, which include glyphosate). Refer to Figure 2-3 for the distribution by herbicide mode of action.

Measures to reduce the development of herbicide resistance are discussed in Section 2.5.

3.12.2 Glyphosate-resistant weeds

As discussed in Section 2.5, herbicide resistance is not a unique or new phenomenon. The development of weeds resistant to a particular herbicide mode of action is an issue that growers have faced for decades. As with other herbicide modes of action, not all weeds respond the same to glyphosate, and some species naturally vary in their tolerance to the herbicide.

Because of the nature of glyphosate and its high degree of specificity, generally speaking, there is a reduced potential that there will be a selection for weed resistance. Glyphosate is a nonselective, foliar-applied, broad spectrum, post-emergent herbicide compared to many other herbicide groups. It operates by binding to a specific enzyme in plants thereby interfering with the plant's required metabolic process. Glyphosate is the only herbicide that binds with this enzyme, and therefore it is highly specific (Cole, 2010a, p5).

Currently in the U.S., there are two known mechanisms of glyphosate resistance. The first is the exclusion mechanism in which glyphosate is either prevented from moving to growing cells or from reaching the target protein. Mechanisms that confer this form of resistance are relatively rare and are not common across plant species. The second mechanism, gene amplification, results from an increase in enzyme gene copies in the plant which leads to higher levels of resistance to glyphosate (Cole, 2010a, p.5).

Accordingly, while glyphosate has been used extensively for over three decades, there have been relatively few cases of resistance development, as compared to many other herbicides and when considering the substantial glyphosate-treated acreage worldwide (approximately 1 billion acres) and the total number of weeds that the herbicide can control. In the U.S., there are ten weed species where glyphosate-resistant biotypes are known to exist in certain areas of the country (19 weeds have been reported to have developed glyphosate resistance at some location worldwide). These resistant weeds represent a relatively small minority of the overall weed population. For example, in 2009, approximately 135 million of the 173 acres of corn, soybeans and cotton in the U.S. were planted with a herbicide tolerant variety, with the most common tolerance trait being glyphosate tolerance (USDA NASS, 2009a). At the same time, only about 6% of the total planted corn, soybean and cotton acres in the U.S. are estimated to

have some level of presence of weeds resistant to glyphosate (Ian Heap as reported by WSSA, 2010).

A weed scientist from the University of Wyoming who specializes in sugar beet weed control, has testified that in the coming years, "it is highly unlikely that the use of glyphosate in connection with GR [glyphosate resistant] sugar beet will result in the same conditions that have led to GR weeds in other GR crops" (Kniss, 2010, p. 3). This is in part because of the fundamentally different growing practices with sugar beet. Kniss reports that more diverse cropping systems (with more rotations and herbicide modes of action), such as those used with sugar beets "are less likely to result in weed resistance issues" (Kniss, 2010, p. 3). Approximately half of the GR weeds noted worldwide to date have been found in non-GR cropping systems (such as orchards). In the U.S., of the confirmed GR weeds, two evolved where there was no GR crop use (roadsides, vineyards, and tree crops) (Kniss, 2010a, p. 2).

GR sugar beet production systems are different than other GR crops, in part because multiple year crop rotations are an integral component of effect weed and pest management programs for the sugar beet crop in all sugar beet growing regions (Kniss, 2010a, p. 3). Given that the sugar beet crop is susceptible to many diseases, nematodes, and insects, multiple crop rotation is required to limit the economic impact of those pests. As such, sugar beet production grower agreements with sugar processers will typically prohibit growers from planting a sugar beet crop in consecutive years (Kniss, 2010a, p. 3).

Instead, sugar beets are generally grown on a three- to four-year rotation. While other GR crops may be included in the rotation with GR sugar beets (with the exact rotation varying in different sugar beet growing regions) (Table 2-2), "the crop rotation in itself will reduce the potential for herbicide resistant weed development due to changing cultural practices between crops (such as planting date, harvest date, tillage practices, etc.)" (Kniss, 2010, p. 4).

As discussed above, the characteristics of glyphosate itself reduce the potential for the development of herbicide resistance as compared to other herbicide families. As such, certain herbicide families have been classified according to their risk of resistant weed development. Beckie (2006) lists acetolactate synthase (ALS) and acetyl CoA carboxylase (ACCase) inhibiting herbicides as "High" risk for resistance development, while glyphosate is considered a "Low" risk herbicide for the development of herbicide resistant weeds. ALS and ACCase inhibiting herbicides are commonly used in conventional sugar beet production, and weeds resistant to these two herbicide groups are widely distributed across sugar beet growing regions of the U.S.

(Kniss, 2010a, p4) (Figure 2-4). Glyphosate tolerant sugar beets can help delay resistance to these herbicides (Kniss, 2010, pp. 4 - 5):

> In fact, glyphosate resistant sugar beet adds to the diversity of herbicide modes of action in many sugar beet crop rotations because it introduces a new mode of action (glyphosate) into the rotation with non-glyphosate-resistant crops, that tend to rely heavily upon acetolactate synthase ("ALS") inhibitors. ALS inhibiting herbicides pose a far greater risk of developing weed resistance than does glyphosate. By adding glyphosate to their crop rotations, growers of GR sugar beet actually decrease the likelihood of developing resistance to ALS inhibitors, just as the use of other crops and alternative modes of action in rotation with GR sugar beet reduce the likelihood of glyphosate resistant weeds.

Use of herbicides with different modes of action, either concurrently or sequentially, is an important defense against weed resistance (Weed Science Society of American [WSSA], 2010b). "Use of a single product or mode of action for weed management is not sustainable. Some of the best and most sustainable approaches to prevent resistance include diversified weed management practices, rotation of modes of action and especially the use of multiple product ingredients with differing modes of action" (WSSA, 2010).

The WSSA reports higher levels of awareness among growers regarding the need to minimize the potential for development of glyphosate resistance: "In a market research study that surveyed 350 growers in 2005 and again in 2009, in response to the question, 'are you doing anything to proactively minimize the potential for resistance to glyphosate to develop,' 67% said yes in 2005 and 87% said yes in 2009" (David Shaw, as reported in WSSA, 2010). "In a 2007 survey of 400 corn, soybean and cotton growers, resistance management programs were often or always used by 70% or more of all three grower groups" (Frisvold and Hurley as reported by WSSA, 2010). There is widespread information available from universities and other sources regarding glyphosate resistance. Public universities (i.e. North Dakota State University, University of Minnesota), herbicide manufacturers (i.e. www.weedresistancemanagement.com, www.resistancefighter.com) and crop commodity groups (i.e. National Corn Growers Association, American Soybean Association) have internet web sites with information on prevention and management of herbicide resistance. An example of information provided by public universities is Dr. Don Morishita, a weed scientist at the University of Idaho, who advises sugar beet growers on weed resistance management strategies (Dumas, 2008). The Sugar Industry Biotech Council provides weed resistance resources on its website. Monsanto includes information on weed resistance management practices in its Technology Use Guide that is mailed annually to all licensed growers. The sugar beet industry associations also hold annual

meetings where weed resistance management practices and other stewardship measures are included as part of the proceedings.

Sugar beet growers in particular have strong financial and practical interests in managing weeds effectively to reduce the development of herbicide resistance in order to maximize yield potential. Sugar beets are a high-value crop, and competition from weeds for moisture and light can negatively impact yields and the overall value of the crop. The development of glyphosate-resistant weeds harms the economic return per acre for the individual farmer and the entire sugar beet industry (Cole, 2010a, p11).

As such, strategies and recommendations to delay the development of glyphosate-resistant weeds have been developed for event H7-1 sugar beets (TUG, Appendix E). Specifically, the TUG recommends the use of "mechanical weed control/cultivation and/or residual herbicides" with event H7-1 sugar beets, where appropriate, and "additional herbicide modes of action/residual herbicides and/or mechanical weed control in other Roundup Ready® crops" rotated with event H7-1 (TUG, 2010, p. 40). In addition to the financial incentive to follow these recommendations, all Roundup Ready technology users, including sugar beet growers, are contractually obligated through the Monsanto Technology Stewardship Agreement to follow the TUG.

3.12.3 Impact summary

Alternative 1

Under Alternative 1, there would be no effect of event H7-1 on the potential for weeds to develop resistance to glyphosate, given that glyphosate use is minimal with conventional sugar beets. Growers would continue to use conventional weed control methods, including other herbicide modes of action, to the extent such conventional herbicides are available (see Section 2.5). A return to conventional herbicides could have consequences for development of further resistance to those herbicides.

As discussed above, glyphosate use in GR sugar beet has proven to be an effective tool against weeds resistant to non-glyphosate herbicides, such as ALS-inhibitors and ACCase-inhibitors. If the planting of H7-1 sugar beets is substantially curtailed, a valuable tool for herbicide resistant weed management will be unavailable to sugar beet growers, and the impact of weeds resistant

to other herbicides may increase, although the impact would likely be small since sugar beets are a relatively small crop (Kniss, 2010a, p. 7).

Alternative 2

Under Alternative 2, impacts, if any, with respect to the development of glyphosate-tolerant weeds in sugar beet crops in the timeframe considered in this ER are expected to be very small. First, sugar beets are a relatively small crop, (event H7-1 accounts for less than one percent of the glyphosate-resistant crops grown in the US), suggesting that the likelihood for the development of new glyphosate-resistant weed populations when compared to other herbicide resistant crops is smaller. Second, as discussed above, the nature of glyphosate itself and the growing practices for sugar beets makes it less likely that new glyphosate-resistant weed populations will develop in sugar beets as a result of the use of glyphosate in sugar beets. Additionally, there is a high level of awareness about the potential for glyphosate resistant weeds and many readily available resources to assist growers with management strategies. Indeed, event H7-1 growers are required to follow Monsanto's TUG, including its recommendations for adopting growing practices aimed at reducing the development of glyphosate-resistant weed populations. Finally, because herbicide resistance is a heritable trait, it takes multiple growing seasons for herbicide tolerant weeds to emerge and become the predominant biotype in a specific area (Cole, 2010a, p. 4). Researchers have concluded that even if growers completely relied on only one herbicide, it is likely to take at least five years for a herbicide-resistant weed population to develop (Kniss, 2010a, p4; Beckie 2006, Neve, 2008; Werth et al., 2008). This is a reason why crop monitoring and follow up by University and industry weed scientist in cases of suspected resistance are important parts of all herbicide resistance stewardship programs.

3.13 PHYSICAL

3.13.1 Land Use

As discussed in Section 2.3, acreage planted in sugar beets in the US has changed little over the past 50 years (since 1961), ranging from a low of 1.1 million acres in 1982 (slightly less than the 2008 acreage) to a high of 1.6 million acres in 1975. Table 3-2 shows planted sugar beet acreage for the last six years. While there have been changes within individual states, overall the range is small. As discussed in Section 2, a small part of the sugar beet crop was event

Table 3-2 Sugar Beet Acres Planted 2005 to 2010

Location	2005	2006	2007	2008	2009	2010
California	44,400	43,300	40,000	26,000	25,300	25,000
Colorado	36,400	42,100	32,000	33,800	35,100	29,800
Idaho	169,000	188,000	169,000	131,000	164,000	169,000
Michigan	154,000	155,000	150,000	137,000	138,000	147,000
Minnesota	491,000	504,000	486,000	440,000	464,000	445,000
Montana	53,900	53,600	47,500	31,700	38,400	42,400
Nebraska	48,400	61,300	47,500	45,200	53,000	46,000
North Dakota	255,000	261,000	252,000	208,000	225,000	227,000
Oregon	9,800	13,100	12,000	6,700	10,600	11,000
Washington	1,700	2,000	2,000	1,600	---	---
Wyoming	36,200	42,800	30,800	29,700	32,400	32,000
US Total	1,299,800	1,366,200	1,268,800	1,090,700	1,185,800	1,174,200

Source: USDA NASS, 2010

H7-1 in 2007, and in 2010, 95 percent of the planted crop was event H7-1. During this time period, the planted sugar beet acreage remained within the range of pre-event H7-1 plantings since 1961.

As discussed in Section 2, sugar beet production is highly structured, vertically integrated, and centered on production facilities that are grower owned.. To maintain a healthy industry, production cannot fluctuate much from year to year: a certain level of production is needed to support the major investment of a processing facility, and a processing facility has limited capacity. The sugar beet grower is bound to the local processing facility and the local processing facility is bound to the sugar beet grower. Barring some unusual disruption in the industry, large fluctuations from year to year would not be expected.

Crop data also provides no indication that the introduction and widespread adoption of GE crops in general has resulted in any significant change to the total US acreage devoted to agricultural production. The acres in the US planted to principal crops, which include corn, sorghum, oats, barley, winter wheat, rye, durum, spring wheat, rice, soybean, peanuts, sunflower, cotton, dry edible beans, potatoes, canola, proso millet, and sugar beets, has remained relatively constant over the past 25 years (USDA NASS, 2010). From 1983 to 1995, the average yearly acreage of principal crops was 328 million (USDA NASS, 2010). Biotechnology-derived crops were

introduced in 1996, and in 2009, 321 million acres of principal crops were planted, which is not a significant change (USDA NASS, 2009a).

Alternative 1

Under Alternative 1, plantings of event H7-1 sugar beet would be limited and only occur under notification or permit issued by APHIS. Growers would not have the option of planting event H7-1 sugar beets. Since sugar beet growers are farmers who also grow other crops, those who would have grown sugar beets could most likely grow some crop, but they could nevertheless suffer significant losses as a result (See Section 2.3). They may choose to grow conventional beets or other crops. A number of factors may influence this decision, including availability of herbicides for conventional sugar beets, availability and cost of specialty cultivating equipment, availability of desirable varieties of sugar beet, and the potential penalty or lost ownership shares in the cooperative for not growing sugar beets. In the short term (the term considered by this ER), Alternative 1 could potentially result in a large decrease in sugar beet production. However, changes in land use would not be expected and the land use is likely to remain agricultural.

Alternative 2

Under Alternative 2, growers who choose to do so could continue to plant event H7-1 sugar beets. Sugar beet acreage would be expected to be similar to the levels of the past 50 years. Land use that is agricultural would be expected to remain so and other land use would not be impacted.

3.13.2 Air Quality and Climate

Alternative 1

Under Alternative 1, plantings of event H7-1 sugar beet would be limited and only occur under notification or permit issued by APHIS. Because the use of glyphosate as a post-emergence herbicide has resulted and is expected to continue to result in an increase in conservation tillage practices, an increase in the use of mechanical tilling would be expected under Alternative 1, if growers would choose to plant conventional sugar beets. If growers would choose other crops, the effects would depend on what the other crops would be. Emissions related to global

warming, ozone depletion, summer smog and carcinogenicity, among others, were found to be lower in glyphosate-tolerant crop systems than conventional systems (Bennett et al., 2004). Therefore, Alternative 1 would be expected to have slightly greater impacts on air quality and climate, if growers planted conventional sugar beets rather than event H7-1 sugar beets.

Alternative 2

Under Alternative 2, growers who choose to do so could continue to plant event H7-1 sugar beets. The continued use of event H7-1 sugar beets may result in continued increases in conservation tillage, as discussed in Section 2 (changing to conservation tillage practice is gradual, as it often requires different management practices and often requires new equipment). Therefore, Alternative 2 would lead to a small but positive impact on air quality and climate relative to Alternative 1.

3.13.3 Surface water quality

Surface water may be impacted from sugar beet production by runoff from sugar beet fields that carries soil particles and herbicides or other pesticides to streams, rivers, lakes, wetlands and other water bodies. As discussed below, based on existing data, the soil component of runoff is a much more important contributor to surface water impacts than is the pesticide component.

Alternative 1

Under Alternative 1, plantings of event H7-1 sugar beet would be limited and only occur under notification or permit issued by APHIS. Under Alternative 1, growers who are now growing event H7-1 sugar beets and who would choose to grow conventional sugar beets would need to use other practices for weed management. These practices would likely consist of some combination of herbicide use and increased tillage (beyond conservation tillage).

If Alternative 1 would result in increased use of tillage for weed control, overall adverse surface water impacts are likely to be greater than with Alternative 2. Tillage causes widespread soil disturbance. Thus, wind and water erosion, topsoil loss and the resulting sedimentation and turbidity in streams are likely to increase with increased tillage. In 2009, based on the states' water quality reports, EPA identified sedimentation and turbidity as two of the top 10 causes of impairment to surface water in the U.S. in general; in 2007, EPA identified sedimentation/siltation as the leading cause of impairment to rivers and streams in particular (EPA, 2009, p. 15; EPA, 2007, p. 9). Although a comprehensive data set has not yet been developed to prove the point, EPA has projected conservation tillage to be "the major soil

protection method and candidate best management practice for improving surface water quality" (EPA, 2002). EPA identifies conservation tillage as the first of its CORE 4 agricultural management practices for water quality protection (EPA, 2008a).

Based on the states' water quality reports to EPA, which EPA makes available through its National Assessment Database, pesticides in general and herbicides in particular are a relatively minor contributor to impairment of surface water in the U.S., compared to sedimentation/siltation and turbidity (EPA 2008b). Of the pesticides that were reported as contributing to impairment, almost all are previously used, highly persistent chemicals that are no longer registered for use in the U.S. Only one herbicide, atrazine, was found (EPA 2008b).

In summary, based on EPA data, herbicides in general are very minor contributors to surface water impairment in the U.S., whereas sedimentation/siltation and turbidity are major contributors. Alternative 1, compared with Alternative 2, would likely result in a different mix of herbicides used and may result in increased tillage. Increased tillage could contribute to adverse surface water impacts through increased runoff of soil particles to surface water bodies.

Alternative 2

Alternative 2 would result in continued application of glyphosate herbicides to event H7-1 sugar beets. Herbicides that adsorb strongly, such as glyphosate, are less likely to degrade or volatilize (USDA APHIS, 2009).

Other herbicides used on sugar beets have varying chemical fates, but, in general, most are more persistent and are characterized by higher mobility in soils, making them more apt to continually contaminate surrounding water systems.

3.13.4 Groundwater quality

Alternative 1

Under Alternative 1, if growers choose to grow conventional sugar beets, the potential for impacts to groundwater would be similar to that prior to the widespread adoption of event H7-1 sugar beets. If herbicides are used that do not bind strongly to soil particles, and have a higher potential to leach into groundwater, the potential for migration to groundwater may be higher than with Alternative 2.

Alternative 2

Because glyphosate binds strongly to soil, and has a low potential to leach into groundwater, it is unlikely to impact groundwater.

3.14 BIOLOGICAL

Potential environmental effects of pesticide use are carefully considered as a part of the FIFRA pesticide registration process. Prior to the approval of a new pesticide or a new use of that pesticide (including a change in pesticide application rates and/or timing) and before reregistering an existing pesticide, EPA must consider the potential for environmental effects and make a determination that no unreasonable adverse effects to the environment will be caused by the new pesticide, new use or continued use.

To make this determination, EPA requires a comprehensive set of environmental fate and ecotoxicological data on the pesticide's active ingredient (US 40 CFR Part 158). EPA uses these data to assess the pesticide's potential environmental risk (exposure/hazard). The required data include both short- and long-term hazard data on representative organisms that are used to predict hazards to terrestrial animals (birds, nontarget insects, and mammals), aquatic animals (freshwater fish and invertebrates, estuarine and marine organisms), and nontarget plants (terrestrial and aquatic).

Information regarding the impacts of glyphosate on the biological environment is summarized below. Additional information on this topic is also being considered in the USDA APHIS Draft Environmental Impact Statement (DEIS) on the Deregulation of Glyphosate Tolerant Alfalfa (Docket No. APHIS-2007-0044). This information is applicable to the use of glyphosate in event H7-1 sugar beet since the maximum single in-crop application rate for GT alfalfa (1.55 lb a.e./A) is greater than the maximum single in-crop application rate for sugar beet (1.125 lb a.e./A).

3.14.1 Plant and Animal Exposure to Glyphosate

Animals

The equivalence of the CP4 EPSPS enzyme to native EPSPS except for tolerance to glyphosate is discussed in Sections 3.1 and 3.11. A number of researchers have conducted laboratory investigations with different types of arthropods exposed to genetically engineered crops containing the CP4 EPSPS protein (Goldstein, 2003; Boongird et al., 2003; Jamornman,

et al., 2003; Harvey et al., 2003). Representative pollinators, soil organisms, beneficial arthropods and pest species were exposed to tissues (pollen, seed, and foliage) from GE crops that contain the CP4 EPSPS protein, to evaluate potential toxicity. These studies, although varying in design, all reported a lack of toxicity observed in various species exposed to these crops (Nahas et al., 2001; Dunfield and Germida, 2003, Siciliano and Germida 1999).

As a part of the reregistration evaluation under FIFRA, EPA conducted an ecological assessment for glyphosate. This assessment compared the results from toxicity tests with glyphosate conducted with various plant and animal species to a conservative estimate of glyphosate exposure in the environment, the Estimated Environmental Concentration (EEC). .

Glyphosate is practically nontoxic to slightly toxic to birds, freshwater fish, marine and estuarine species, aquatic invertebrates and mammals and practically nontoxic to honey bees (which are used to assess effects on nontarget insects in general) (EPA, 1993, pp. 50, 38 - 40, 45, 47, 48 - 50). Glyphosate has a low octanol-water coefficient, indicating that it has a tendency to remain in the water phase rather than move from the water phase into fatty substances; therefore, it is not expected to accumulate in fish or other animal tissues.

In the Reregistration Eligibility Decision (RED) for glyphosate (EPA, 1993, p. 53), the exposure estimates were determined assuming an application rate of 5.0625 lb a.e., which exceeds the maximum labelled use rate for a single application for agricultural purposes. When the EECs were calculated for aquatic plants and animals, the direct application of this rate to water was assumed. Based on this assessment, EPA concluded that effects to birds, mammals, fish and invertebrates are minimal based on available data (EPA, 1993).

The glyphosate end-use products used in agriculture contain a surfactant to facilitate the uptake of glyphosate into the plant (Ashton and Crafts, 1981). Depending on the surfactant used, the toxicity of the end-use product may range from practically nontoxic to moderately toxic to fish and aquatic invertebrates (EPA, 1993, pp. 42 - 45). For this reason, the 1993 Glyphosate RED stated that some formulated end-use products of glyphosate needed to be labeled as "Toxic to fish" if they were labeled for direct application to water bodies. Due to the associated hazard to fish and other aquatic organisms, glyphosate end-use products that are labeled for applications to water bodies generally do not contain surfactant, or contain a surfactant approved for direct application to water bodies.

Soil Microorganisms

Microorganisms produce aromatic amino acids through the shikimate pathway, similar to plants. Since glyphosate inhibits this pathway, it could be expected that glyphosate would be toxic to microorganisms. However, field studies show that glyphosate has little effect on soil microorganisms, and, in some cases, field studies have shown an increase in microbial activity due to the presence of glyphosate (USDA FS, 2003).

Based on the data available on glyphosate usage, chemical fate, and toxicity, glyphosate is not expected to pose an acute or chronic risk to the following categories of wildlife: (EPA, 1993)

- birds,
- mammals,
- terrestrial invertebrates,
- aquatic invertebrates, and
- fish
- soil microorganisms

Alternative 1

Under Alternative 1, the potential for impacts to animal species may be greater than with Alternative 2 because of the return to greater use of additional herbicides, potentially with higher toxicities.

Alternative 2

As stated previously, Alternative 2 is expected to result in the continued use and application of glyphosate-based herbicide formulations. This could result in continued glyphosate exposure to animal species within and adjacent to those fields through drift, as discussed previously, and a decrease in exposure to other herbicides from runoff and/ or drift (USDA APHIS, 2009).

. . . . .Considering the potential for aquatic exposure to glyphosate formulations from terrestrial uses, EPA recently evaluated the effect of glyphosate and its formulations on another amphibian species, the California red-legged frog, and concluded that aquatic exposure to

glyphosate or its formulations posed no risk to this threatened species (EPA, 2008b). Because EPA considered a wide range of application rates in their evaluation for the red-legged frog, this conclusion can also be applied to amphibians exposed to glyphosate from applications on event H7-1 sugar beet. Any possible adverse impacts to amphibians resulting from the deregulation of event H7-1 sugar beet may be offset by the shift from other herbicides used in sugar beet cultivation, which are considered to have higher environmental impacts in general. . Additionally, amphibian habitat in watersheds where event H7-1 sugar beet is produced could be improved through conservation tillage, resulting in decreased soil erosion, decreased sedimentation in runoff, and decreased turbidity in ponds, lakes, and rivers fed by surface waters.

Plants

Glyphosate is a non-selective herbicide with post-emergence activity on essentially all annual and perennial plants. As discussed in Section 3.1.1, this activity is due to inhibition of EPSPS, an enzyme involved in aromatic amino acid synthesis. As with any herbicide, a risk exists that spray drift could pose issues for plants on the borders of the target fieldHowever, EPA takes the potential for spray drift into account when conducting the risk assessment it uses to establish pesticide application rates and direction for use, which are designed to minimize spray drift risks.. As discussed earlier, glyphosate binds tightly to agricultural soils and is not likely to move offsite dissolved in water. Moreover, glyphosate is not taken up from agricultural soil by plants. However, because drift is a potential means of exposure to non-target plants adjacent to an event H7-1 sugar beet field; Monsanto conducted a threatened and endangered (TE) species risk assessment to evaluate the impacts to plants (and animals) from the use of glyphosate-based herbicides in conjunction with glyphosate-tolerant plants. The complete assessment was submitted to APHIS and has been reviewed by APHIS scientists to support the petition for deregulation of glyphosate-tolerant alfalfa. The assessment is available on the APHIS, BRS website at http://www.aphis.usda.gov/biotechnology/alfalfa_documents.shtml

The assessment identified some plant, but no animal, species for which glyphosate when aerially applied could pose issues in areas bordering fields in certain locations where sugar beets are grown. To address any such risks, Monsanto developed Pre-Serve, a web-based program designed to eliminate any potential impacts on TE plants resulting from the agricultural use of herbicides that contain glyphosate.

Pre-Serve instructs growers to observe specific precautions when spraying glyphosate herbicides on Roundup Ready® crops near TE plant species that may be at risk. Only a very small percentage of glyphosate applications will require mitigation measures. This is because the vast majority of U.S. cropland is outside of the Pre-Serve Use Limitation Areas – areas where threatened or endangered plant species may be present – and most glyphosate applications are made using ground application equipment at rates below 3.5 pounds of active ingredient per acre (lb a.e./acre), which will not impact the TE plant species.

Growers who are licensed to purchase and use seeds containing Roundup Ready® technology are required contractually to follow the requirements in Monsanto's Technology Use Guide. This includes the requirement to access the Pre-Serve website (www.pre-serve.org) or contact Monsanto before applying glyphosate-based herbicide products to crops grown from these seeds. This website will guide growers and applicators through a user-friendly, four-step process to determine whether their fields are located within Use Limitation Areas and, if so, to identify the mitigation measures that must be taken. For fields located within Use Limitation Areas, the following mandatory steps must be taken to reduce potential risks to TE plant species:

- Ground applications are limited to rates of less than 3.5 lb a.e./acre (most uses).
- Aerial applications may be prohibited in buffer zones along perimeters of fields. The size of buffer zones can be minimized by employing a coarser spray droplet size.
- In specified counties, aerial applicators will be required to observe a new maximum use rate of 0.92 lb a.e./acre (26 fl. oz/A Roundup PowerMAX® or WeatherMAX®) if using medium spray droplets[39], but can apply the current full labeled rate (1.55 lb a.e./acre or 44 fl. oz/acre of Roundup PowerMAX or WeatherMAX) if using coarse spray droplets.

In addition to the instructions provided by Pre-Serve, mitigations from local, state or federal protection programs and/or landowner agreements may apply. Monsanto's licensees are required to follow these measures where applicable. .

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[39] In counties where listed plant species observations were present, but not within 250 ft of a relevant land use, actual separation distance was not assessed. In these counties aerial application rates with medium sized droplets are restricted to 0.92 lb a.e./acre to avoid exposure to listed TE plant species that might be within 417 ft of the application area, and thus within an area where aerial application at 1.55 lb a.e./acre using medium-sized spray droplets would present a potential risk based on the Tier 1 assessment. This restriction will be eliminated in many cases by further distance assessments.

The Pre-Serve web-based system, as described above, enables growers and applicators to take steps where necessary to avoid potential effects to TE plant species from application of glyphosate-based agricultural herbicides.

Alternative 1

Under Alternative 1, the rates and volumes of glyphosate applications on sugar beet crops would likely return to the level of use that existed prior to the deregulation of event H7-1 sugar beets. Growers would use an array of other herbicides, some of which may be applied at greater volumes compared to glyphosate. The herbicides used in conventional sugar beet systems have been found, in general, to have somewhat greater human health or environmental impacts than glyphosate (USDA, 2004). This is consistent with the EPA decision to grant reduced risk status for glyphosate use in glyphosate-tolerant sugar beets.**Error! Bookmark not defined.** Comparison of results from terrestrial and aquatic plant studies with predicted exposure from herbicide use suggests that most of the herbicides used in conventional sugar beet systems may have more effect than glyphosate on aquatic or terrestrial plant species. These herbicides are selective herbicides that kill only particular groups of plants such as annual grasses, perennial grasses, or broadleaf weed species and thus require the use of more than one herbicide to achieve satisfactory weed control.

Alternative 2

Alternative 2 is expected to result in continued use and application of glyphosate-based herbicide formulations. This could result in some incidental glyphosate exposure to terrestrial and aquatic plants in the vicinity of event H7-1 beet fields by spray drift. The EPA has concluded that glyphosate use on event H7-1 sugar beet can be considered to pose reduced risk compared to other herbicides used for weed control in conventional sugar beets.[40]

. . Hundreds of millions of acres of other GT crops have been treated with glyphosate for over ten years with minimal impact to adjacent non-target terrestrial plants including crops when appropriate drift minimization measures are practiced. Because glyphosate binds strongly to soil particles and has no herbicidal activity after binding to soil, no effects on aquatic plants will result from surface water runoff from glyphosate use on event H7-1 sugar beet in accordance with labeled directions for use.. Conservation tillage and no tillage practices that are possible

[40] A reduced risk decision is made at the use level based on a comparison between the proposed use of the pesticide and existing alternatives currently registered on that use site. A list of decisions regarding Reduced Risk Status can be found at: http://www.epa.gov/opprd001/workplan/reducedrisk.html

when glyphosate is used have the potential to decrease surface water runoff and sedimentation which further benefits aquatic organisms.

3.14.2 Threatened and Endangered Species

As the action agency for pesticide registrations EPA has the responsibility to conduct an assessment of effects of a registration action on endangered species. The EPA Endangered Species Protection Program web site, http://www.epa.gov/espp/, describes the EPA assessment process for endangered species. Some of the elements of that process, generally taken from the web site, are summarized below.

When registering a pesticide or reassessing the potential ecological risks from use of a currently registered pesticide, EPA evaluates extensive exposure and ecological effects data to determine how a pesticide will move through and break down in the environment. Risks to birds, fish, invertebrates, mammals and plants are routinely assessed and used in EPA's determinations of whether a pesticide may be licensed for use in the U.S.

EPA's core pesticide risk assessment and regulatory processes ensure that protections are in place for all populations of nontarget species. Because endangered species may need specific protection, EPA has developed risk assessment procedures described in the Overview of the Ecological Risk Assessment Process (U.S. EPA, 2004d, p. 7) to determine whether individuals of a listed species have the potential to be harmed by a pesticide, and if so, what specific protections may be appropriate. EPA's conclusion regarding the potential risks a pesticide may pose to a listed species and any designated critical habitat for the species, after conducting a thorough ecological risk assessment, results in an "effects determination."

As a part of the endangered species effects assessment for the California red-legged frog, EPA evaluated the effect of glyphosate at rates up to 7.95 lb a.e./A on fish, amphibians, aquatic invertebrates, aquatic plants, birds, mammals, and terrestrial invertebrates. This assessment determined that at the maximum application rate for in-crop applications of glyphosate to GT sugar beets (1.125 lb a.e./A) there would be no effects of glyphosate on the following taxa of threatened and endangered species: fish, amphibians, birds, and mammals. EPA also determined that glyphosate formulations would have no effect on threatened or endangered fish, amphibians, birds, and mammals. Although not specifically discussed in the assessment, from the EEC's and effects endpoints presented, it can also be determined that there would be

no effects of glyphosate or its formulations on threatened or endangered vascular aquatic plants, and aquatic invertebrates (EPA, 2008b).2008). non-endangered small .H7-1 .

Monsanto has designed a web-based program (www.Pre-Serve.org), designed to ensure no effect of glyphosate applications on threatened and endangered plant species. Pre-Serve instructs growers to observe specific precautions when spraying glyphosate herbicides on glyphosate-tolerant crops near threatened and endangered plant species that may be at risk. According to the U.S. Fish and Wildlife Service Endangered Species website, there are no TE terrestrial invertebrates in Colorado, Idaho, Nebraska, North Dakota, South Dakota, and Wyoming. [41] In other states, TE small terrestrial invertebrates, if present, are at no more risk than from applications of glyphosate to conventionally grown sugar beets.

Alternative 1

Under Alternative 1, the potential for impacts to threatened and endangered species may be greater than with Alternative 2 because of the use of certain herbicides with potentially higher toxicities.

Alternative 2

As indicated, EPA is responsible for and has previously conducted analyses regarding glyphosate impacts. Only two percent of glyphosate is applied aerially to all agricultural crops in the US (USDA APHIS, 2009). Given that aerial application in event H7-1 sugar beets is not expected to be any different than other agricultural production systems, approximately two percent of glyphosate used in event H7-1 sugar beets is expected to be applied aerially. Additionally, the use of buffer zones, based on the Pre-Serve program, between the sugar beet field and any potential threatened or endangered plant populations can prevent any adverse impacts due to drift of glyphosate from aerial applications (USDA APHIS, 2009), so that there will be no effect on endangered species.

We evaluated the potential for deleterious effects or significant impacts on non-target organisms, including those on the US Fish and Wildlife Service (USFWS) threatened and endangered species list, from cultivation of event H7-1 sugar beet and its progeny. The enzyme CP4 EPSPS that confers glyphosate tolerance is from the bacterium Agrobacterium sp. strain CP4. This gene is similar to the gene that is normally present in sugar beets and is not known

[41] http://www.fws.gov/endangered/species/index.html

to have any toxic property (Schneider, 2003). Field observations of event H7-1 sugar beet event H7-1 revealed no negative effects on non-target organisms (Schneider, 2003). The lack of known toxicity for this enzyme suggests no potential for deleterious effects on beneficial organisms such as bees and earthworms. The high specificity of the enzyme for its substrates makes it unlikely that the introduced enzyme would metabolize endogenous substrates to produce compounds toxic to beneficial organisms (Schneider, 2003).

3.15 HUMAN HEALTH AND SAFETY

3.15.1 Consumer Health and Safety

Alternative 1

Under Alternative 1, the potential for impacts to consumers may be greater than with Alternative 2 because of the use of herbicides with higher toxicities.

Alternative 2

The general public is not at a high risk of exposure to substantial levels of glyphosate under typical use conditions (EPA, 1993; USDA FS, 2003). Under Alternative 2, exposure to glyphosate would not increase beyond that currently experienced, since 95 percent of sugar beet is already event H7- 1. According to the EPA Glyphosate Fact Sheet (1993) glyphosate is of relatively low oral and dermal acute toxicity and has been placed in Toxicity Category III for these effects (Toxicity Category I indicates the highest degree of acute toxicity, and Category IV the lowest). The acute inhalation toxicity study was waived by EPA because glyphosate is nonvolatile and available adequate inhalation studies with end-use products show low toxicity.

The use of glyphosate herbicide does not appear to result in adverse effects on development, reproduction, or endocrine systems in humans and other mammals. Under present and expected conditions of use, glyphosate herbicide does not pose a health risk to humans (EPA, 1993).

Additionally, the nature of glyphosate residue in plants and animals is adequately understood, and studies with a variety of plants indicate that uptake of glyphosate from soil is limited. The material that is taken up is readily translocated throughout the plant. In animals, ingested or absorbed most glyphosate is essentially not metabolized and is rapidly eliminated in urine and feces. Enforcement methods are available to detect residues of glyphosate in or on plant commodities, in water, and in animal commodities (EPA, 1993).

EPA conducted a dietary risk assessment for glyphosate based on a worst-case risk scenario, that is, assuming that 100 percent of all possible commodities/acreage were treated, and assuming that tolerance-level residues remained in/on all treated commodities. Based on the assessment, EPA concluded that the chronic dietary risk posed by glyphosate food uses is minimal (EPA, 1993).

The addition of another GT crop to agricultural production may lead to a greater chance that a GT crop, including GT sugar beets may be grown near other food crops. This could lead to higher exposure to glyphosate in the diet of the general public because there would be a greater chance for glyphosate residue to reach food crops via spray drift. Nonetheless, such increase risk of exposure to glyphosate residue will not result in increased risks to the general population because the current upper estimates of risk are based on highly conservative fruit and vegetable intake rates with an assumed high estimated amount of glyphosate residue. Glyphosate is registered for use as a direct application to weeds in several fruits and vegetables and tolerances are established in the consumable commodities of these crops. The current aggregate dietary risk assessment completed by EPA concludes there is no concern for any subpopulation regarding exposure to glyphosate, including the use on many fruits and vegetables and GT sugar beet (71 FR 76180, 2006). Moreover, the potential exists for decreases in the applications and subsequent residues of more toxic herbicides if GT sugar beet is deregulated.

3.15.2 Hazard Identification and Exposure Assessment for Field Workers

Alternative 1

Under Alternative 1, the potential for impacts to field workers may be greater than with Alternative 2 because of the increased need for hard labor to remove weeds and the use of herbicides with higher toxicities.

Alternative 2

According to the RED document for glyphosate (EPA, 1993), glyphosate is of relatively low oral and dermal acute toxicity. For this reason, glyphosate has been assigned to Toxicity Categories III and IV for these effects (i.e., Toxicity Category I indicates the highest degree of acute toxicity, and Category IV the lowest). An acute inhalation study was waived by EPA because glyphosate is a non-volatile solid, and the studies conducted on the end-use product formulation are considered sufficient (EPA, 1993). Expert toxicological reviews from US EPA (1993) and the World Health Organization (WHO, 2004) are in agreement that glyphosate does not pose

any human acute exposure concerns for dietary exposures and thus negated the need to establish an acute reference dose.

With regard to subchronic and chronic toxicity, one of the more consistent effects of exposure to glyphosate at high doses is reduced body weight gain compared to controls. Body weight loss is not seen in multiple subchronic studies, but has at times been noted in some chronic studies at excessively high doses ≥ 20,000 ppm in diet (WHO, 2004). Other general and non-specific signs of toxicity from subchronic and chronic exposure to glyphosate include changes in liver weight, blood chemistry (may suggest mild liver toxicity), and liver pathology (USDA FS, 2003). Glyphosate is not considered a carcinogen; it has been classified by EPA as a Group E carcinogen (evidence of non-carcinogenicity for humans) (EPA, 1993; 2006).

EPA has considered in its human health analysis the potential applicator and bystander exposure resulting from increased glyphosate use. Based on the toxicity of glyphosate and its registered uses, including use on glyphosate-tolerant crops, EPA has concluded that occupational exposures (short-term dermal and inhalation) to glyphosate are not of concern because no short-term dermal or inhalation toxicity endpoints have been identified for glyphosate (71 FR 76180, 2006).

Additional evidence to support the EPA conclusion can be found in the *Farm Family Exposure Study*, a biomonitoring study of pesticide applicators conducted by independent investigators (Acquavella, et al. 2004). This biomonitoring study determined that the highest estimated bodily adsorption of glyphosate as the result of routine labeled applications of registered glyphosate-based agricultural herbicides to crops, including glyphosate-tolerant crops, was approximately 400 times lower than the RfD established for glyphosate. Furthermore, investigators determined that 40 percent of applicators did not have detectable exposure on the day of application, and 54 percent of the applicators had an estimated bodily adsorption of glyphosate more than 1000 times lower than the RfD (Acquavella, *et al.*, 2004). Use patterns and rates for glyphosate tolerant sugar beet are typical of most glyphosate agronomic practices. Therefore, the deregulation of glyphosate-tolerant sugar beet would not significantly increase the exposure risk to pesticide applicators.

Finally, the biomonitoring study also found little evidence of detectable exposure to individuals on the farm who were not actively involved in or located in the immediate vicinity of labeled applications of glyphosate-based agricultural herbicides to crops. Considering the similarity of the use pattern and application rates of the glyphosate products in this study compared to those

registered for use on glyphosate-tolerant sugar beet and glyphosate-tolerant crops in general, bystander exposure attributed to the use of glyphosate on glyphosate-tolerant crops is expected to be negligible. Therefore, the use of currently registered pesticide products containing glyphosate in accordance with the labeling will not pose unreasonable risks or adverse effects to humans or the environment. In general, the herbicidal activity of glyphosate is due primarily to a metabolic pathway that does not occur in humans or other animals, and, thus, this mechanism of action is not directly relevant to the human health risk assessment. EPA considers glyphosate to be of low acute and chronic toxicity by the dermal route of exposure. Glyphosate is considered a Category IV dermal toxicant and is expected to cause only slight skin irritation (USDA APHIS, 2009).

3.16 ECONOMIC IMPACTS

3.16.1 Sugar beet processing

Approximately 54% of the U.S. domestic sugar production comes from sugar beets (USDA Farm Service Agency [FSA], 2010). Refined sugar from sugar beets is the product of a multi-year cycle and involves beet seed suppliers, sugar beet growers, sugar beet processors, sugar users and consumers (USDA FSA, 2010). As part of that process, beet seed suppliers plant the commercial sugar beet seed crop in the fall of Year 1, which produces the commercial seeds harvested in the fall of Year 2. The commercial seed is processed over the winter and sold to sugar beet growers who plant it in the spring. Sugar beet growers harvest the beet root in the fall of Year 3 and deliver them to beet processing facilities owned by the beet processors. Beet sugar is extracted by beet processors beginning in the fall of Year 3 and throughout Year 4. The sugar produced from these beets is purchased by food manufacturers and consumers (USDA FSA, 2010).

Of the sugar beet root crop planted in the spring of 2009, 95 percent was reported to be event H7-1 sugar beet seed. This is also the same for the sugar beet root crop planted in the spring of 2010, and harvested in the fall of 2010. This represents 98 percent of the sugar beet root crop outside of California, where, as discussed in Section 2, event H7-1 has not been grown (USDA FSA, 2010). The harvesting of the 2010 root crop will begin between late August and early September, depending of the projected size of the sugar beet crop. The bigger the crop, the earlier the harvest will begin to make sure it is completed before the ground freezes. By late August, most of the crop's sugar will have been contracted for sale (USDA FSA, 2010). The economic impact of preventing that crop from being harvested and processed is discussed below.

3.16.2 USDA's role in sugar marketing

The domestic sugar market is closely managed by USDA's sugar program and therefore, not governed solely by supply and demand. USDA controls domestically produced sugar through the Flexible Sugar Marketing Allotment Program, and controls foreign imports through the raw and refined sugar tariff-rate quotas (TRQs). Unlimited amounts of refined sugar can be imported under a high duty of 16.3 cents per pound and raw sugar of 15.36 cents per pound. Under section 156 of the Federal Agriculture Improvement and Reform Act of 1996, as amended by the Food Conservation, and Energy Act of 2008 (the Farm Bill), and the Harmonized Tariff Schedule of the United States (HTS), USDA is required to establish a range of acceptable market conditions, which means maintaining a price floor in potentially oversupplied situations by removing surplus supply, and maintaining "adequate supply" in potentially undersupplied market situations (USDA FSA, 2010). The minimum raw and refined sugar prices that the sugar program must support are the levels that would cause sugar beet and sugarcane processors to forfeit their sugar that was put up as collateral under the USDA sugar nonrecourse loan program. Sugar nonrecourse loans support raw cane sugar prices at 21 cents per pound and refined beet sugar prices at 24 cents per pound. The nonrecourse loans support price because forfeiting the sugar collateral completely extinguishes the borrower's debt, thus sugar beet and sugarcane processors are assured of getting at least the USDA loan proceeds for their sugar. Loan collateral forfeiture also removes surplus sugar out of the market because the government is limited by the Farm Bill in its sugar disposal options (USDA FSA, 2010).

At the other end of the range, the objective of maintaining "adequate supply" (as described in the Farm Bill) or "adequate supply at reasonable prices" (described in HTS) requires USDA to increase supply under tight markets, which will make domestic prices lower than they would otherwise be. However, there is no maximum sugar price strategy stipulated in federal law, as there is a minimum sugar price. Under the Flexible Sugar Marketing Allotments Program, the sugar beet processors are guaranteed a market share of 46 percent of the domestic market. If the sector cannot fulfill its quota, USDA is required to increase imports to maintain adequate supply (USDA FSA, 2010).

3.16.3 Economic Impacts

Alternative 2 is not expected to result in adverse economic impacts. Growers and seed producers would continue to use and sell event H7-1 seed and crops and seek return on their investments. This section discusses the economic impacts of Alternative 1.

Economic implications of a halt in event H7-1 sugar beet cultivation

Should the unrestricted use of event H7-1 sugar beets be impacted, effectively removing the product from the market, an estimated 4.25 million tons of beet sugar would be removed from the market (USDA FSA, 2010). This sugar is expected to supply about 40 percent of U.S. sugar consumption during 2011.

Because the federal government has a major effect on sugar supply, and hence sugar price, the market reaction to a reduction in refined beet sugar is somewhat determined by USDA's supply management response. USDA has recently reacted to two similar, but smaller, events in 2005 and 2008 (temporary loss of cane refineries) that demonstrate the potential effect from a reduction in sugar. In both cases, U.S. refined sugar prices averaged about 18 cents per pound above the world refined sugar price, even as USDA increased the world refined quota to moderate U.S. sugar prices (USDA FSA, 2010). However, an action that effectively precludes further planting, cultivation, processing, or other use of event H7-1 sugar beets would cause greater disruption and greater harm to the U.S. sugar market than caused by the 2005 or 2008 disruptions because the reduction, 4.25 million tons, is 20 times larger than the loss of supply in 2005 and 10 times larger than the loss in 2008 (USDA FSA, 2010). Prices increased substantially in those years, but were never high enough to cause sugar to be imported off the world market at the high tariff rate of 16.3 cents per pound. Under the scenario where event H7-1 sugar beet is effectively precluded, world sugar could enter under a high tariff and set the refined price in the U.S. market (USDA, 2010).

Additionally, USDA learned from the temporary loss of cane refineries in 2005 and 2008 that many U.S. food manufacturers have difficulty using imported refined sugar because of differences in product quality or packaging. After the 2005 and 2008 events, a new business developed to clean, repackage, or liquefy imported refined sugar for domestic use. This was required because domestic food companies would not use the crystallized imported sugar in its original packaging (USDA FSA, 2010).

U.S. sugar cane refiners are expected to run at near full capacity in 2011, therefore, they will not have the capacity to refine imported raw cane sugar to replace the 4.25 million tons of beet

sugar lost. Normally, USDA would increase the raw sugar TRQ to alleviate domestic sugar shortages. However, in 2011, domestic needs for sugar would have to be filled by increasing refined sugar imports by 6 times from an average of 690,000 tons over the past 3 years (USDA FSA, 2010). This increase in refined sugar imports may cause an extensive disruption in the current refined sugar distribution system. For example, the 2.6 million tons would require about 250,000 containers on at least 330 ships by the end of September 2010 (USDA FSA, 2010).

If sugar beet root crop growers cannot harvest, they will experience an economic hardship because they will have incurred all the costs of producing the 2010 root crop except for harvesting. Further, they would incur the cost to destroy the crop to prepare the land for the next crop, and to prevent the sugar beet root crop from overwintering and reaching the flowering stage in 2011. Sugar beet processors are currently contracting FY 2011 beet sugar at 38 cents per pound (USDA FSA, 2010). Therefore, sugar beet growers and cooperative owners would also experience lost revenue estimated at $3.23 billion (4.25 million tons X 0.38 $/lb X 2000 lbs/ton) (USDA FSA, 2010).

Sugar beet processing factories, and the local economies organized around them, would experience economic hardship if beet processing factories were prevented from purchasing, processing, or selling sugar from event H7-1 sugar beets. The sugar beet processing factories would be idled, thousands of jobs would be lost and the livelihoods of many rural communities would be at stake (USDA FSA, 2010)Dr. Richard Sexton, an agricultural economist and an authority on agricultural cooperatives, recently conducted an investigation as to what the economic impact would be on growers and processors if the growing of GT sugarbeets was enjoined in 2011 and 2012. His results are particularly insightful because they rely, in part, on direct interviews and written surveys with each of the eight sugarbeet processing companies. Dr Sexton estimated that the consequences on a ban of GT sugarbeets in 2011 are: 1) 8 of 21 sugarbeet processing plants would close (and unlikely to reopen); 2) grower crop income would be reduced by approximately $253 million; 3) sugarbeet processor worker salaries would be reduced by about $138 million dollars; and 4) the adverse economic impact on the local economies where sugarbeets are grown and processed would be approximately $1.1 billion. If a ban continued through 2012, Dr. Sexton estimated that processor full-time and seasonal employment would be lowered by approximately 1,570 workers, grower income would be reduced further by another $282 million and the adverse economic impact would be $964 million in lower net revenue to growers and their communities (Sexton 2010). Also, a. A 2004 study by the University of Idaho found that if sugar beet production and processing ceased in Idaho and

alternative crops were planted instead, Idaho would lose over 3,000 jobs and farm incomes would decline (given returns to corn, wheat, and other production options based on 2004 projections). Sugar beet growers generally produce other crops, and their land would not remain idle; they have the equipment and expertise to produce other crops. The longer-term concern, however, is in terms of the impact on infrastructure, as some companies may not survive closing down for one season (USDA FSA, 2010).

Additionally, individual sugar cooperative shareholders are significantly penalized for not fulfilling their contract. For example, one cooperative member stated that, "I currently own 485 shares that are valued at $350 each and I am required to produce 485 acres of sugar beets annually to Western for processing. By contract, I am subject to an economic penalty of $350 per share if my annual share of sugar beets is not delivered to Western for processing. Western has enforced this penalty against growers in the past" (Hofer, 2010).

Sugar Beet Seed Production and Availability

Only sugar beets grown from approved varieties can be utilized by growers for sugar beet production. The processor seed committee will establish a list of approved varieties from which growers may select. Once a variety has been approved for commercial production by the processor seed committee, the seed producer produces the seed in the quantities projected to be sold to the processor's growers. Seed suppliers must predict years in advance the likely demand for new varieties. If a seed supplier over predicts likely demand, the excess seed may be inventoried for a period that does not exceed the viability of the seed (Manning, 2010).

The approved varieties have undergone extensive multi-year planting trials to determine how well each variety tolerates exposure to particular diseases and pests known to infest the growing region, particular growing conditions such as exposure to particular weather conditions, and the variety's ability to deliver acceptable yields per ton and sugar content (Manning, 2010).

The approved variety list denotes sugar beet varieties that may be delivered to the processor for sugar production. As a cooperative member, a grower has a contract to deliver sugar beet from a specified number of acres. Sugar beet varieties that do not make the approved variety lists cannot be delivered to the processor for sugar production because they do not meet the standards set forth by the processor. A grower is not permitted by the processor to plant a sugar beet variety not on the approved list (Manning, 2010).

When event H7-1 sugar beet was deregulated in 2005, the industry began production of event H7-1 sugar beet seed. The majority of conventional seed varieties and seed available for the 2011 crop year originated prior to 2007. Consequently, some approved varieties, including the genetic traits of those seed, and the inventory of some conventional seed now available were based on production decisions made many years ago (Manning, 2010). Certain seed producers have not engaged in new varietal development for conventional sugar beet since 2006/2007. Some processors have no conventional seed on their current approved variety list, while others still list some conventional seed varieties (Manning, 2010). Manning looked at the availability of sugar beet seed should event H7-1 sugar beet seed be unavailable. Based on Manning's analysis, all sugar beet growing regions in the U.S. would experience a shortfall of sugar beet seed to plant (Manning, 2010). The USDA FSA (2010) also stated that domestically-produced conventional sugar beet seed is in short supply because domestic seed companies have reduced production of conventional beet seed in recent years.

Sugar beet seed produced outside the United States may not be suitable for commercial production in the U.S. Certain sugar beet seed varieties produced in the European Union (EU) or elsewhere have not undergone extensive multi-year variety trials in the U.S to determine if that variety meets the standards for disease resistance required by growers and beet processors.

The limited availability of conventional seed could severely restrict plantings of sugar beets in 2011 and sugar production in 2012 (USDA FSA, 2010). Based on information provided by sugar beet seed producers and buyers, UDSA FSA (2010) estimates that prohibiting the harvest of event H7-1 sugar beet seed in 2010, would reduce projected sugar beet root crop acreage by 37 percent in 2011. Based on that estimate, the reduction in acres planted for sugar beet production would lower beet sugar production by an estimated 1.6 million tons in 2012 (lost acreage with unchanged yields and unchanged sugar recovery)(USDA FSA, 2010). The economic impact of a reduction in beet sugar supply on consumer costs and grower incomes in 2012 would be severe (USDA FSA, 2010). However, the severity would be mitigated depending on the degree to which sugar users and consumers reduce their consumption of sugar or switch to non-sugar sweeteners. Manufacturers and consumers will have time to reduce their beet sugar use and manufacturing costs if a decision to prohibit event H7-1 sugar beets is announced at least a year before it affects domestic supply. USDA FSA (2010) estimates that U.S. demand for sugar could fall 1 percent due to the higher sugar costs in 2012.

If event H7-1 sugar beet seed could not be planted in the spring of 2011 to grow the root crop, the 2012 U.S. refined sugar price is expected to rise from 33 cents per pound to 41 cents per pound, which includes transportation, product modification costs necessary to be suitable for American users, and the premium the U.S. Sugar Program provides domestic growers. Sugar users and consumers would pay a total of $1.6 billion additional for sugar in 2012 even if they consume less due to the higher sugar prices. Growers and processors are projected to experience a loss of 700 million in lost 2012 sugar beet and sugar sales (USDA FSA, 2010).

A summary of the projected costs from an action that effectively precludes the planting, cultivation, and processing of event H7-1 sugar beets on sugar users and consumers and sugar beet growers and processors over the next two years is shown in Table 3-3.

Herbicide Shortages

The availability of herbicides is another factor that will likely affect a growers' decision to plant conventional sugar beet varieties. The advent of event H7-1 sugar beets caused a decline in the use of certain herbicides that were used with conventional sugar beet crops. The manufacturers of these herbicides have reduced production. Should growers plant conventional seed, the herbicides may not be available unless the manufacturers ramp up production to meet anticipated demands. This decision must be made far in advance of when the herbicides would be needed (Manning, 2010).

Table 3-3. Production Loss and Project Costs from an event H7-1 Sugar Beet Injunction

Parent Seed Planted	Commercial Seed Produced	Commercial Seed Planted	Harvest/ Sales Year	Expected Sugar Production	Sugar Production Lost	Cost to Growers	Cost to Users/ Consumers
				(1,000 tons)		(Million $)	
fall 2008	fall 2009	spring 2010	2011	4,477	4,253	3,232	2,972
fall 2009	fall 2010	spring 2011	2012	4,396	1,627	658	1,592

Source: USDA FSA, 2010

3.17 SOCIAL AND ECONOMIC IMPACTS ON RED BEET AND CHARD GROWERS

Seed Production

In contrast to the very significant social and economic impacts identified in section 3.16 if H7-1 sugarbeet cultivation were halted, the effect of continued cultivation subject to the proposed interim measures would be minimal. As indicated in Section 2.8, most red beet and chard seed crops are grown in areas outside the Willamette Valley in Oregon where the large majority of sugarbeet seed crops are grown. The geographic limitations in the interim measures would preclude H7-1 seed cultivation in those areas and remove any chance of gene transfer between the crops. In the Willamette Valley, there is limited production of red beet and chard seed. See Section 2.8. The majority of such seed producers in those areas have agreed to and comply with the existing Willamette Valley Specialty Seed Association isolation distances for those areas, and have not reported issues or losses due to genetic transfer. There appears to be only very limited organic red beet and chard seed production in the Willamette Valley, and no indication of genetic transmission in the years since H7-1 seed cultivation began on a large scale in 2006. Although one identified organic grower has chosen to grow chard (among other organic crops) in the Western margins of the Valley, that grower has tested his crops on repeated occasions with PCR tests over multiple years and found no indication of gene flow from H7-1 crops.

In addition, in the years since 2006, seed companies producing H7-1 seed in the Willamette Valley have increasingly employed a "gene on the female" nonpollinator approach for H7-1 production fields, meaning that those fields shed virtually zero pollen that could transmit H7-1 genetic material. As a consequence, as discussed in Section 1.5, even an organic grower who chose to market and sell chard seed with a "zero tolerance" for H7-1 genetic material would face no risk from such fields.

The organic community's consensus Non-GMO Project Working Standard does not require zero tolerance – it contemplates a tolerance for GE traits in verified Non-GMO seed or 0.25%. The National Organic Program is a process-based standard; no organic grower has ever lost organic certification due to an unintended trace presence of a GE trait. Further, if an organic grower sensitive to H7-1 genetic material wished to ensure "zero tolerance," relatively inexpensive testing is available to do so, and common seed production methodologies can be employed to maintain a "zero tolerance" for organic seed if desired. This is discussed in Sections 1.5 and 1.6. There is also no realistic prospect of mechanical mixing between red beet and chard seed

and H7-1 seed because the two production processes are entirely separate. As discussed in Section 2.7, seed is processed in different facilities, and no common equipment is used.

Under APHIS's proposed interim measures, each seed company producing H7-1 would be subject to third party audits of compliance with the standards to ensure that the measures remained in place and were effective. Accordingly, Alternative 2 would have no or negligible social or economic impacts on red beet and chard crops, Alternative 1, by contrast, would have highly significant negative impacts on nationwide sugarbeet production, as discussed above.

Root Crop Production

As indicated above, including in Sections 2.8 there is little or no overlap of H7-1 root crop production and red beet and chard seed production. To the extent certain red beet or chard seed savers may exist in root crop production areas (none have been identified), the measures for roguing bolters and related stewardship render the potential for genetic transmission from H7-1 negligible. As indicated, Alternative 2 would have no or negligible social or economic impacts on red beet and chard crops, By contrast, Alternative 1 would have highly significant impacts across multiple growing areas.

Consumer Acceptance of the Sugar from Event H7-1 Sugar beets

Since wide-scale production of event H7-1 sugar began, there has been no indication of significant concern regarding acceptance of H7-1 sugar producers of food products with sugar derived from these products or from consumers. The sugar is identical chemically to sugar from conventional sugarbeets (Baker, 2010a, pp. 2-3; Hoffman, 2010a, p. 10). In addition as indicated in Section 3.11.2, food and feed issues have been reviewed by FDA. This FDA review has not been challenged

For any consumers who are nevertheless concerned about the source of this sugar, there are alternatives available. Cane sugar and other sweeteners are readily available for instance. And certain public interest groups, including the Institute for Responsible Technology, have publicized the readily available alternatives to sugarbeet sugar and other sweeteners derived from biotechnology (Burkam, 2010, p. 58).

CUMULATIVE IMPACTS

This section discusses the cumulative impacts that may be associated with Alternative 2, when combined with other recent past, present, and reasonably foreseeable future actions within the affected environment. Alternative 2 is expected to be maintained for a short time duration, and an EIS will specifically address the environmental impacts associated with full deregulationin . Cumulative impacts that will occur before the EIS is completed are expected to be negligible. By contrast, as indicated in Section 3.16, the specific and cumulative impacts of Alternative 1 are expected to be significant for growers nationwide.

Cumulative impacts occur when the effects of an action are added to the effects of other actions occurring in a specific geographic area and timeframe. The cumulative impact analysis follows CEQ's guidance: Considering Cumulative Effects Under the National Environmental Policy Act (CEQ, 1997). The steps associated with the analysis include:

- Specify the class of actions for which effects are to be analyzed.
- Designate the appropriate time and space domain in which the relevant actions occur.
- Identify and characterize the set of receptors to be assessed.
- Determine the magnitude of effects on the receptors and whether those effects are accumulating.

4.1 CLASS OF ACTIONS TO BE ANALYZED

This analysis addresses large, regional and national-scale trends and issues that have impacts that may accumulate with those of the proposed interim measures.

4.2 GEOGRAPHIC AND TEMPORAL BOUNDARIES FOR THE ANALYSIS

As described in Section 2, over the past 10 years, the number of acres planted annually in sugar beets in the US has ranged from 1.1 to 1.4 million (USDA ERS, 2009, Table 14). Event H7-1 sugar beets are produced in five major regions in the US, and commercial production of seeds takes place in the Willamette Valley of Oregon. Therefore, the spatial domain for past, present, and reasonably foreseeable future actions considers the five growing regions for issues associated with growing event H7-1 sugar beets; the Willamette Valley for issues associated with seed production; and the nation, and in some cases international areas, for issues associated with consumption of sugar beet food and feed products. Also, as indicated, the measures at issue would apply for a limited time period, estimated at less than 2 years.

RESOURCES ANALYZED

Issues evaluated in this cumulative impacts analysis include some of the resource areas discussed in Chapters 2 and 3 including land use, air quality and climate, water quality,

biological, and human health and safety. In addition, specific topics analyzed include: cumulative impacts related to any possibility of development of glyphosate resistant weeds, and cumulative impacts of potential increased glyphosate usage with the cultivation of glyphosate tolerant crops.

4.3 PARTIAL.CUMULATIVE IMPACTS RELATED TO THE DEVELOPMENT OF GLYPHOSATE RESISTANT WEEDS

Glyphosate offers many benefits to the grower as a weed control product. Glyphosate controls a broad spectrum of grass and broadleaf weed species present in sugar beet production fields, has flexible use timings, and when used in glyphosate-tolerant crops, has a very high level of crop safety (see petition 03-323-01p, Tables VII-4 and VII-4, pages 90 and 92, respectively). As the adoption of glyphosate-tolerant crops has grown, the use of glyphosate has increased over the past several years. With the increased use of glyphosate, there is also the potential for increased selection pressure for the development of glyphosate-resistant weeds (Section VIII).

Because a glyphosate-based herbicide program is currently being used with event H7-1 sugar beet, glyphosate use for event H7-1 is not expected to increase beyond current levels, as market penetration is already at 95 percent. Current levels of glyphosate use in event H7-1 sugar beets are a minor (approximately 0.7 percent) amount of total US glyphosate use. Additionally, with Alternative 2, growers still would have the currently available weed control tools (e.g., non-glyposate herbicides and cultural practices described in Section VII.B of petition 03-323-01p on page 88) needed on a small scale to manage any glyphosate-resistant weeds, whether they are present in sugar beet or other crop production fields.

4.4 CUMULATIVE IMPACTS OF POTENTIAL INCREASED GLYPHOSATE USAGE WITH THE CULTIVATION OF GLYPHOSATE TOLERANT CROPS

Studies of the relationship between genetically engineered crops and herbicide use has shown that an increase in glyphosate tolerant crops can result in a decrease in mechanical tillage (Brimner et al., 2005; Fernandez-Cornejo, 2006; Gianessi and Reigner, 2006; Kleter et. al., 2007; Sankula, 2006; Johnson et al., 2008). The potential cumulative impact from this reduction in mechanical tillage is discussed in the following sections.

According to the USDA ERS (2009), US farmers have adopted genetically engineered crops widely since their introduction in 1996. Soybeans and cotton genetically engineered with herbicide-tolerant traits have been the most widely and rapidly adopted GE crops in the US, followed by insect-resistant cotton and corn. Figure 4-1 shows the percentage of acres of genetically engineered crops in the US between 1996 and 2009.

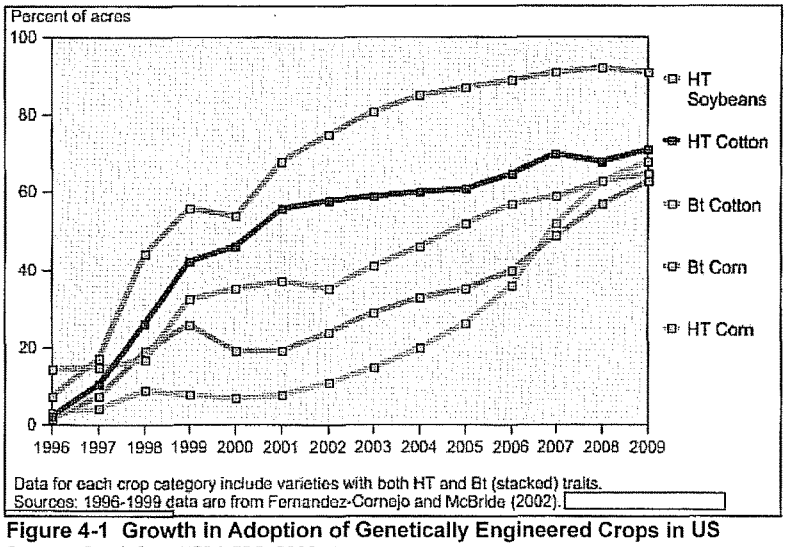


Figure 4-1 Growth in Adoption of Genetically Engineered Crops in US
Source: Graph from USDA ERS, 2009

Herbicide-tolerant crops, which are engineered to survive application of specific herbicides that previously would have damaged the crop , provide farmers with a broader variety of options for effective weed control. Based on USDA survey data, herbicide tolerant soybeans went from 17 percent of US soybean acreage in 1997, to 68 percent in 2001 and 91 percent in 2009. Plantings of herbicide tolerant cotton expanded from approximately 10 percent of US acreage in 1997 to 56 percent in 2001 and 71 percent in 2009. The adoption of herbicide tolerant corn, was slower in previous years, but has reached 68 percent of US corn acreage in 2009 (USDA ERS, 2009).

Corn growers use the largest volume of herbicides. Approximately 96 percent of the 62.2 million acres used for growing corn in the 10 major corn-producing States were treated with

more than 164 million pounds of herbicides in 1997 (USDA ERS, 2009). Soybean production in the US also uses a large amount of herbicides. Approximately 97 percent of the 66.2 million soybean acres in the 19 major soybean producing States were treated with more than 78 million pounds of herbicides in 1997 (USDA ERS, 2009). Cotton production relies heavily on herbicides to control weeds, often requiring applications of two or more herbicides at planting and postemergence herbicides later in the season (Culpepper and York, 1998). Close to 28 million pounds of herbicides were applied to 97 percent of the 13 million acres devoted to upland cotton production in the 12 major cotton-producing States in 1997 (USDA ERS, 2009).

Pesticide use on corn and soybeans has declined since the introduction of GE corn and soybeans in 1996. Several studies have analyzed the agronomic, environmental, and economic effects of adopting GE crops, including actual pesticide use changes associated with growing GE crops (McBride and Brooks, 2000; Fernandez-Cornejo, Klotz-Ingram, and Jans, 1999, 2002; Giannessi and Carpenter, 1999; Culpepper and York, 1998; Marra et al., 1998; Falck-Zepeda and Traxler, 1998; Fernandez-Cornejo and Klotz-Ingram, 1998; Gibson et al., 1997; ReJesus et al., 1997; Stark, 1997). Many of these studies have concluded that herbicide use is reduced with herbicide-tolerant varieties (USDA ERS, 2009).

Studies conducted by the USDA also show an overall reduction in pesticide use related to the increased adoption of GE crops. Based on the adoption of GE crops between 1997 and 1998 (except for herbicide-tolerant corn, which is modeled for 1996-97), the decline in pesticide use was estimated to be 19.1 million acre-treatments, 6.2 percent of total treatments (USDA ERS, 2009). Most of the decline in pesticide acre treatments was from less herbicide used on soybeans, accounting for more than 80 percent of the reduction (16 million acre-treatments) (USDA ERS, 2009).

The adoption of herbicide-tolerant crops such as event H7-1 sugar beets, glyphosate-tolerant soybeans, and glyphosate-tolerant corn results in the substitution of glyphosate for previously used herbicides. The glyphosate tolerant crops allow farmers to limit and simplify herbicide treatments based around use of glyphosate, while a conventional weed control program can involve multiple applications of several herbicides. In addition, and more importantly, herbicide-tolerant crops often allow farmers to use more benign herbicides (USDA ERS, 2009).

There are known benefits associated with the use of glyphosate herbicides compared to herbicides currently used by sugar beet producers. Glyphosate has documented favorable characteristics with regard to risk to human health, non-target species, and the environment

(Malik et al., 1989; Geisy et al., 2000; Williams et al., 2000). Glyphosate is classified by the EPA as a Group E pesticide (evidence of non-carcinogenicity for humans) (57 FR 8739). In 1998, the EPA granted Reduced Risk status for an expedited review of the submitted residue data package supporting the use of glyphosate, as Roundup Ultra herbicide (EPA Registration No. 524-475) for use in glyphosate tolerant sugar beets. Reduced Risk status was granted by EPA based on a detailed hazard comparison of glyphosate to alternative herbicides available for weed control in sugar beet production (Reduced Risk petition document: MRID 44560501), and an overall conclusion that weed control with Roundup Ultra herbicide offers a substantial benefit to sugar beet growers in the form of reduced risk to human health, non-target species, and the environment.

4.4.1 Land Use, Air Quality and Climate

As discussed in Section 3, sugar beet acreage has fluctuated little for the past 50 years, was not impacted by the introduction of event H7-1, and is not expected to be impacted by continued use of event H7-1. Therefore, as discussed in Section 3, Alternative 2 is not expected to impact land use. As it is not expected to directly or indirectly impact land use, Alternative 2 would not have cumulative impacts on land use.

As discussed in Section 3, Alternative 2 is expected to continue to have small positive impacts on air quality and climate, primarily resulting from reduced tillage. Consequently, Alternative 2 is not expected to have any adverse cumulative impacts on air quality or climate.

4.4.2 Water Quality

As discussed in Section 3, the advent of glyphosate tolerant crops and the use of post-emergent herbicides that could be applied over a crop during the growing season have facilitated the use of conservation tillage farming practices, since weeds could be controlled after crop growth without tilling the soil (USDA ERS, 2009). The use of glyphosate tolerant crops (particularly soybeans) has intensified that trend since it often allows a more effective and less costly weed control regime than using other post-emergent herbicides (USDA ERS, 2009; Carpenter and Gianessi, 1999).

The impact of conservation tillage (including no-till, ridge-till, and mulch-till) in controlling soil erosion and soil degradation is well documented (Edwards, 1995; Sandretto, 1997). By leaving substantial amounts of plant matter over the soil surface, conservation tillage 1) reduces soil erosion by wind; 2) reduces soil erosion by water; 3) increases water infiltration and moisture

retention; 4) reduces surface sediment and water runoff; and 5) reduces chemical runoff (USDA ERS, 2009).

Glyphosate maypotentially be found in surface water runoff when erosion conditions lead to the loss of surface particles. However, as discussed in Section 3, partial deregulation of glyphosate tolerant crops typically leads to an increase in conservation tillage and no tillage systems, which would result in less mechanical disturbance of the soil during sugar beet cultivation and thereby decrease the loss of surface soil. Because of this, and the fact that glyphosate binds strongly to soil particles, no-tillage and conservation tillage are expected to further reduce the likelihood of any impact surface water runoff (Wiebe and Gollehon, 2006). Therefore, no cumulative adverse impacts to surface water or groundwater are anticipated.

4.4.3 Biological

For non-target terrestrial species, available ecological assessments in EPA RED (EPA, 2003) documents or registration review summary documents provide the support that the use of glyphosate represents reductions in chronic risk to birds compared to trifluralin and sethoxydim, in acute risk to small mammals in comparison to EPTC, in chronic risk to mammals from quizalofop-p-ethyl, in acute risk to endangered birds and mammals from pyrazon, and in chronic risk to mammals and potentially birds from cycloate. For all other sugar beet herbicide products, as well as glyphosate, no significant risks to birds or other non-target terrestrial species were indicated in the available information.

For non-target aquatic species, Tables 4-1, 4-2, and 4-3 provide summaries of the estimated exposure and hazard information for the traditional herbicides used in conventional sugar beet production, and present quantitative comparisons of the derived Risk Quotients. Exposure, defined as the EEC, was calculated for all products using the standard assumptions (assuming aerial application) of 5 percent drift of spray applied to a one-acre field onto water and 5 percent runoff from 10 treated acres into a one-acre pond six feet in depth. Herbicide treatments were based on the maximum single application rate taken from product labels. Hazard information (LC50 or EC50) for each active ingredient was taken from the EPA Ecotoxicology One-Liner Database (if available) or other EPA source documents and summarized in Tables 4-1, 4-2 , and 4-3 as the upper and lower values from the range of values reported. Hazard information for the end-use formulated products is generally not readily available, thus this analysis is a comparison based solely on the active ingredients. Any label warnings and other available hazard and/or risk descriptions for non-target aquatic species are also included. The Risk

Quotient is determined for each active ingredient by dividing the EEC by the hazard (LC50 or EC50) value.

Plants potentially at risk from the use of glyphosate are potentially at risk from the use of any herbicide. Like most herbicides, plants are highly sensitive to glyphosate. Monsanto has developed a program named Pre-Serve to address aerial spraying in areas where threatened plants may be located. Following label use instructions and use limitations described in Pre-Serve swould address any such risk of exposure. Federal law requires pesticides to be used in accordance with the label.. Because glyphosate binds strongly to soil particles, conservation tillage and no tillage practices provide additional assurance that the impact to aquatic plants through decreasing soil-laden runoff are negligible.

The labels for products containing desmedipham, phenmedipham, sethoxydim, clethodim and trifluralin include warnings of toxicity or adverse effects to fish, and/or aquatic invertebrates and/or aquatic plants. Risk Quotients that exceed the Trigger Value of 0.5 for aquatic animals and 1.0 for aquatic plants are highlighted in bold text in Tables 4-1, 4-2, and 4-3 as exceeding a Level of Concern, based on EPA Ecological Effects Rejection Analysis and Deterministic Risk Characterization Approach. Current sugar beet herbicide products containing triflusulfuron, trifluralin, and pyrazon are shown to exceed these Levels of ConcernAs supported by the EPA designation of reduced risk for application of glyphosate to H7-1 sugar beet,. glyphosate is a more environmentally preferred herbicide compared to other herbicides currently used in sugar beet production since glyphosate is generally less toxic and has favorable degradation properties.

4.4.4 Human Health and Safety

A tolerance increase was required to support approval for the use of glyphosate in the event H7-1 sugar beet-cropping system compared to the limited pre-emergent use of glyphosate in conventional sugar beet production. However, the potential health effects of pesticide residues that may be present in food, regardless of whether they result from uses in conventional or glyphosate tolerant crops, are carefully considered by EPA before establishing maximum residue limits or tolerances.

Before establishing a tolerance in an agricultural commodity, EPA must find that the potential resulting residues covered by the proposed tolerance will be "safe". Section 408(b)(2)(A)(ii) of the FFDCA [21 USC 346a(b)(2)(A)(i)] defines "safe" as a reasonable certainty that no harm will result from aggregate exposure to the pesticide chemical residue. As part of this determination,

the total maximum theoretical level of residue present in all food commodities with approved uses for the pesticide must not exceed the EPA established Reference Dose (RfD), or chronic Population Adjusted Dose (cPAD). Following a comprehensive review of the results of toxicological studies conducted on the pesticide, the RfD is set by applying appropriate uncertainty factors to the most appropriate No-Observed-Adverse-Effect-Level (NOAEL).

In 1999, EPA conducted a dietary exposure risk assessment and concluded that the incremental dietary exposure associated with the use of glyphosate on glyphosate tolerant sugar beet did not pose a concern to human health (64 FR 18360, 1999). . .

Table 4-1 Comparison of Potential Effects of Glyphosate and Sugar Beet Herbicides on Freshwater Fish

Active Ingredient	Max. lb/acre (single appl.)	EEC[1] (ppm)	Fish LC_{50} (a.i.)[2] Range (ppm)		Fish Risk Quotient[3] Range		Classification / Label Warnings
			low	high	worst	best	
Glyphosate	1.125	0.038	45	140	0.0008	0.0003	
Clethodim	0.09	0.003	19	>33	0.0002	<0.0001	
Clopyralid	0.25	0.008	104	125	0.0001	0.0001	
Cycloate	4.0	0.135	4.5	7	0.03	0.02	
Desmedipham	1.2	0.040	1.7	6	0.024	0.007	Toxic to fish.
EPTC	4.2	0.142	11.5	27	0.012	0.005	
Ethofumesate	3.6	0.121	0.75	>320	0.16	<0.0004	
Phenmedipham	0.6	0.020	1.41	3.98	0.014	0.005	
Pyrazon	7.3	0.246	NA	NA	NA	NA	
Quizalofop-p-ethyl	0.17	0.006	0.17	10.72	0.034	0.00	
Sethoxydim	0.47	0.016	170	265	0.0001	0.0001	Toxic to aquatic organisms.
Trifluralin[4]	0.72	0.024	0.0084	0.210	**2.9**	0.12	Extremely toxic to freshwater, marine and estuarine fish.
Triflusulfuron	0.08	0.0027	<640	<760	>0.000004	>0.000004	

NA = Information not available

[1] EEC refers to the Estimated Environmental Concentration, which assumes that a one-acre pond, six feet deep receives 5% drift from a one-acre field and 5% runoff from a 10-acre field.

[2] Aquatic LC_{50} values obtained from the 2010 EPA Ecotoxicology One-Liner Database.

[3] Risk Quotient is EEC/LC_{50}. Risk Quotient **Bolded** if > 0.5 = Level of Concern [criteria from EPA Ecological Effects, Rejection Analysis]. Risk Quotients >0.1 result in classification for Restricted Use (http://www.epa.gov/oppefed1/ecorisk_ders/toera_risk.htm#Deterministic).

[4] Toxicity values are from the Trifluralin Reregistration Eligibility Document, United States Environmental Protection Agency, April 1996.

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Table 4-2 Comparison of Potential Effects of Glyphosate and Sugar Beet Herbicides on Freshwater Aquatic Invertebrates

Active Ingredient	Max. lb/acre (single appl.)	EEC[1] (ppm)	Invertebrate EC_{50} (a.i.)[2] Range (ppm)		Invertebrate Risk Quotient[3] Range		Classification / Label Warnings
			low	high	worst	best	
Glyphosate	1.125	0.038	134	780	0.0003	0.00005	
Clethodim[4]	0.09	0.003	20.2	NA	0.0002	NA	
Clopyralid	0.25	0.008	225	NA	0.00004	NA	
Cycloate	4.0	0.135	2.6	24	0.052	0.006	
Desmedipham	1.2	0.040	1.88	NA	0.021	NA	
EPTC	4.2	0.142	3.5	66	0.040	0.002	
Ethofumesate	3.6	0.121	64	294	0.002	0.0004	
Phenmedipham	0.6	0.020	3.2	14	0.006	0.001	Toxic to fish and aquatic organisms.
Pyrazon	7.3	0.246	NA	NA	NA	NA	
Quizalofop-p-ethyl	0.17	0.006	2.12	6.4	0.003	0.001	
Sethoxydim	0.47	0.016	78	NA	0.0002	NA	Toxic to aquatic organisms.
Trifluralin[5]	0.72	0.024	0.56	2.2	0.043	0.011	Extremely toxic to aquatic invertebrates.
Triflusulfuron	0.08	0.0027	960	NA	0.000003	NA	

NA = information not available or not applicable

[1] EEC refers to the Estimated Environmental Concentration, which assumes that a one-acre pond, six feet deep receives 5% drift from a one-acre field and 5% runoff from a 10-acre field.

[2] Aquatic Invertebrate EC_{50} values obtained from the 2010 EPA Ecotoxicology One-Liner Database.

[3] Risk Quotient is EEC/EC_{50}. Risk Quotient **Bolded** if > 0.5 = Level of Concern [criteria from EPA Ecological Effects, Rejection Analysis]

[4] EC_{50} value is from a study using a 25.6% ai concentration.

[5] Toxicity values are from the Trifluralin Reregistration Eligibility Document, United States Environmental Protection Agency, April 1996.

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Table 4-3 Comparison of Potential Effects of Glyphosate and Sugar Beet Herbicides on Aquatic Plants (Algae and Duckweed)

Active Ingredient	Max. lb/acre (single appl.)	EEC[1] (ppm)	Aquatic Plant EC_{50} (a.i.)[2] Range (ppm)		Aquatic Plant Risk Quotient[3] Range		Classification / Label Warnings
			low	high	worst	best	
Glyphosate	1.125	0.038	0.8	38.6	0.047	0.001	
Clethodim	0.09	0.003	1.34	>11.4	0.0023	<0.0003	May pose hazard to federally listed endangered plants.
Clopyralid	0.25	0.008	6.9	NA	0.001	NA	
Cycloate	4.0	0.134	NA	NA	NA	NA	
Desmedipham	1.2	0.040	0.044	>0.33	0.909	<0.123	
EPTC	4.2	0.141	1.36	41	0.104	0.003	
Ethofumesate	3.6	0.121	>2.76	>39	<0.044	<0.003	
Phenmedipham	0.6	0.020	0.19	>0.32	0.106	<0.064	Toxic to aquatic organisms.
Pyrazon	7.3	0.245	0.17	>4.6	**1.441**	<0.053	
Quizalofop-p-ethyl	0.17	0.006	>0.082	>1.77	<0.069	<0.004	
Sethoxydim	0.47	0.016	>0.27	>5.6	<0.059	<0.003	Toxic to aquatic organisms.
Trifluralin	0.72	0.024	0.015	5.0	**1.60**	0.005	Extremely toxic to aquatic invertebrates.
Triflusulfuron[4]	0.08	0.0027	0.0028	0.123	0.96	0.022	

NA = information not available or not applicable.

[1] EEC refers to the Estimated Environmental Concentration, which that a one-acre pond, six feet deep receives 5% drift from a one-acre field and 5% runoff from a 10-acre field.

[2] Aquatic EC_{50} values obtained from the 2010 EPA Ecotoxicology One-Liner Database except for the values for phenmedipham which are from the Reregistration Eligibility Decision for Phenmedipham..

[3] Risk Quotient is EEC/EC_{50}. Risk Quotient **Bolded** if > 1.0 = Level of Concern [criteria from EPA Ecological Effects, Rejection Analysis].

[4] Toxicity values are from the Regulatory Note REG99-03 from the Pest Management Regulatory Agency of Canada.

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In a recent risk assessment supporting establishment of certain new food crop tolerances for glyphosate, EPA estimated that chronic (daily dietary) exposure to glyphosate from all food and water sources would use only 2 percent of the glyphosate RfD (1.75 mg/kg/day) for the general US population and 7 percent of the RfD for the highest potentially exposed subgroup population (71 FR 76180, 2006).

The cumulative impacts from use of glyphosate on sugar beets was considered. ,

Biomonitoring of pesticide applicators conducted by independent investigators has shown that bodily adsorption of glyphosate as the result of routine, labeled applications of registered glyphosate-based agricultural herbicides to crops, including to glyphosate tolerant sugar beet, was thousands of times less than the allowable daily intake level established for glyphosate (Acquavella et al., 2004). Given similarity to current use pattern, herbicide label rates, and the percentage of cultivate acres for sugar beets, the continued use of event H7-1 sugar beet through partial deregulation will not significantly increase the exposure risk to pesticide applicators. Furthermore, EPA, the European Commission, the WHO, and independent scientists have concluded that glyphosate is not mutagenic or carcinogenic, not a teratogen nor a reproductive toxicant, and that there is no evidence of neurotoxicity associated with glyphosate (EPA, 1993; EC, 2002; WHO, 2004, and Williams et al., 2000).

Bystander exposure to glyphosate as a result of pesticide application to event H7-1 sugar beet would be negligible, since such applications would occur in an agricultural setting in relatively rural sugar beet fields, not in an urban setting.

Presented below is an brief, comparative analysis of the hazard/risk characteristics of glyphosate, the active ingredient in Roundup WeatherMAX® herbicide (EPA Registration No. 524-537), to the most commonly used herbicides applied in conventional sugar beet production, based on total pounds of active ingredient applied (USDA-NASS, 2001). A detailed assessment of the potential chronic human health risks compared to traditional products will not be presented in this comparison. The assessment is based on information obtained from various sources, including product-specific labeling, EPA Reregistration Eligibility Documents (RED, EPA, 1993), EPA RED Fact Sheets, product-specific Federal Register publications, the EPA

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Ecotoxicology One-Liner database[42], the USDA Pesticide Properties database[43], and other public sources of product-specific toxicological and environmental profile information. The assessment shows that in the majority of cases, weed control with glyphosate, formulated and sold as Roundup WeatherMAX herbicide, in the event H7-1 sugar beet system offers the benefit of less risk from potential exposure for applicators and handlers of concentrated product and a reduced potential to impact non-target species and water quality.

Table 4-4 provides a comparison of product-specific labeling for herbicides commonly used for weed control in sugar beet production, including required precautionary statements associated with acute exposure hazards and environmental risk concerns. Although most alternative products carry the same signal word as Roundup WeatherMAX herbicide (CAUTION), the associated precautionary statements of each of the alternative herbicide products are indicative of toxicity findings that represent a greater acute exposure risk than Roundup WeatherMAX. Nearly every sugar beet herbicide product evaluated has more restrictive requirements for the use of Personal Protective Equipment (PPE) than those required for Roundup WeatherMAX herbicide, indicating a greater need to reduce the risk of acute exposure, and, in some cases, the risk of longer-term or chronic exposure, for applicators and handlers of these other products.

The comparative analyses provided in this section are summarized in Table 4-5 and show those areas for which glyphosate (designated with a checkmark ✓), using Roundup WeatherMAX herbicide in the comparison, offers the benefit of potential risk reduction compared to the most commonly used sugar beet herbicides in sugar beet production. In this cumulative comparison, glyphosate offers potential benefits over all the traditional sugar beet herbicides in at least one and up to four risk assessment categories. These comparisons demonstrate the benefits to applicators, mixers and non-target organisms from the use of glyphosate in the event H7-1 sugar beet system.

4.4.5 Summary of Potential Cumulative Impacts from Increased Use of Glyphosate

When considering the impact that the use of glyphosate in the event H7-1 sugar beet system could have on the human environment in conjunction with the use of glyphosate in other glyphosate tolerant crops already being cultivated in the same affected environments, the facts suggest that this use will have little or noadditive effect Additionally, use of glyphosate.

[42] EPA Ecotoxicology One-Liner database: http://www.ipmcenters.org/Ecotox/index.cfm
[43] USDA Pesticide Properties database: ttp://www.ars.usda.gov/Services/docs.htm?docid=14199

Alternatively, this has the potential to reduce risks to the affected environment from the use of other, more harmful, herbicides. This is supported by the assessment of the environmental and worker safety hazards associated with glyphosate when compared to other available herbicides used for weed control in sugar beet production. Based on such an assessment, EPA granted reduced risk status for this use of glyphosate, and expedited the review of supporting residue data. Therefore, there is no reasonably anticipated adverse cumulative impact on human health or the environment from the use of glyphosate associated specifically with the deregulation of event H7-1 sugar beets

For a discussion of coexistence of H7-1 and conventional beta species crops, see Sections 1.6 and 2.4..

Table 4-4 Alternative Herbicides for Weed Control in Sugar Beets - Label Comparison / Exposure Mitigation

Active Ingredient(s)	Product Brand	Label Signal Word	Sugar Beet PHI[a] (days)	Max. lb ai/acre (single appl.)	Max. lb. ai/acre (season)	Label Precautionary Statements / Special Directions / Other Information	Applicator and Handler PPE[b] Required to Mitigate Exposure Risks
Glyphosate	Roundup WeatherMAX	Caution	30	1.125	6	Causes moderate eye irritation. Harmful if inhaled. Do not store in steel. Four resistant weed biotypes confirmed to date.	Long-sleeved shirt, long pants, shoes plus socks. When handling this concentrated product or its application solutions of 30% or greater, must also wear chemical-resistant gloves.
Clethodim[c]	Select 2 EC or Prisim	Warning	40	0.09	0.25	Causes substantial, but temporary, eye injury. Harmful if swallowed or inhaled. Potential skin sensitizer. Warnings and precautions for runoff and drift. Use of the product may pose hazard to federally listed endangered plant species. Warnings for repeated use leading to selection of resistant weed biotypes. Crop injury warnings.	Long-sleeved shirt, long pants, shoes plus socks, chemical-resistant gloves, protective eyewear. Do not reuse heavily contaminated clothing.
Clopyralid	Stinger	Caution	45	0.25	0.25	Causes eye injury. Harmful if inhaled or absorbed through skin. Warning for leaching to groundwater under certain conditions. Crop injury warnings for 1) use of treated plant material or manure from animals grazed in treated areas, as mulch or compost; and 2) spreading of treated soil. Up to 18-month rotation restrictions to many crops due to risk of injury; field bioassay recommended.	Long-sleeved shirt, long pants, waterproof gloves, shoes plus socks.

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Table 4-4 Alternative Herbicides for Weed Control in Sugar Beets - Label Comparison / Exposure Mitigation

Active Ingredient(s)	Product Brand	Label Signal Word	Sugar Beet PHI[a] (days)	Max. lb ai/acre (single appl.)	Max. lb. ai/acre (season)	Label Precautionary Statements / Special Directions / Other Information	Applicator and Handler PPE[b] Required to Mitigate Exposure Risks
Cycloate	Ro-neet	Caution	NA; preplant incorporation	4	4	Harmful if swallowed. Avoid contamination of food or feed. Soil incorporation or soil injection required. Crop injury concerns dependent on soil type.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus socks. Added PPE in California for a non-closed system; for mixers/loaders: chemical resistant clothing, full face respirator; for applicators: coveralls, plus half-face respirator, 93 gallon limit for 21-day period.
Desmedipham[d]	Betanex	Caution	75	1.2	1.92	Harmful if swallowed. Causes moderate eye irritation. Prolonged or frequent repeated skin contact may cause allergic reaction. This product contains the toxic inert ingredient isophorone. This product is toxic to fish. Do not apply where runoff is likely to occur. Sugar beet injury possible under many situations.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus socks, protective eyewear.

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Table 4-4 Alternative Herbicides for Weed Control in Sugar Beets - Label Comparison / Exposure Mitigation

Active Ingredient(s)	Product Brand	Label Signal Word	Sugar Beet PHI[a] (days)	Max. lb ai/acre (single appl.)	Max. lb. ai/acre (season)	Label Precautionary Statements / Special Directions / Other Information	Applicator and Handler PPE[b] Required to Mitigate Exposure Risks
Desmedipham/ phenmedipham	Betamix	Warning	75	1.2	1.92	Causes substantial, but temporary, eye injury. Harmful if swallowed or absorbed through skin. This product contains the toxic inert ingredient isophorone. This product is toxic to fish and aquatic organisms. Drift and runoff...may be hazardous to fish and aquatic organisms. Physical hazard: Combustible. Sugar beet injury possible under many situations; evening applications recommended. Rotation restriction of 120 days for cereals.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus socks, protective eyewear.
EPTC[e]	Eptam	Caution	NA; preplant incorporation or very early postemergence	4.2	5.6	Harmful if swallowed. Avoid breathing spray mist. Incorporation or soil injection required unless applied through irrigation.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus socks.
Ethofumesate	Nortron	Caution	90	3.6	4	Harmful if swallowed, inhaled or absorbed through skin. Rotation restrictions of 6 to 12 months for crops other than sugar beets or ryegrass. Do not graze livestock on treated crops.	Long-sleeved shirt, long pants, waterproof gloves, shoes plus socks.

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Table 4-4 Alternative Herbicides for Weed Control in Sugar Beets - Label Comparison / Exposure Mitigation

Active Ingredient(s)	Product Brand	Label Signal Word	Sugar Beet PHI[a] (days)	Max. lb ai/acre (single appl.)	Max. lb. ai/acre (season)	Label Precautionary Statements / Special Directions / Other Information	Applicator and Handler PPE[b] Required to Mitigate Exposure Risks
Pyrazon	Pyramix DF	Caution	0	7.3	7.3	Harmful if swallowed, inhaled or absorbed through skin. Avoid breathing dust or spray mist. Causes moderate eye irritation. Significant crop injury warning statements, depending on soil moisture level, soil type (organic matter content, loam, sandy, etc.), and temperature at time of application, application method, and tank mix products.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus socks. Do not reuse clothing heavily contaminated with this product's concentrate.
Quizalofop-p-ethyl	Assure II	Danger	45 days, except 60 days for feeding of tops	0.17	0.17	Causes severe eye irritation. May irritate skin, nose and throat. May be harmful if absorbed through skin, swallowed or inhaled. This product contains petroleum-based distillates. Rotation restriction of 120 days for crops not labeled. Need spray adjuvant added.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus sock, protective eyewear. Do not reuse clothing heavily contaminated with this product's concentrate.
Sethoxydim[f]	Poast	Warning	60	0.40	0.8	Causes substantial, but temporary, eye injury. Harmful if swallowed. This product is toxic to aquatic organisms. Crop injury warnings. Multiple confirmed resistant weed biotypes.	Coveralls over short-sleeved shirt and short pants, chemical-resistant gloves, chemical-resistant footwear, protective eyewear, chemical-resistant headgear for overhead exposure, chemical-resistant apron for cleaning, mixing, loading.

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Table 4-4 Alternative Herbicides for Weed Control in Sugar Beets - Label Comparison / Exposure Mitigation

Active Ingredient(s)	Product Brand	Label Signal Word	Sugar Beet PHI[a] (days)	Max. lb ai/acre (single appl.)	Max. lb. ai/acre (season)	Label Precautionary Statements / Special Directions / Other Information	Applicator and Handler PPE[b] Required to Mitigate Exposure Risks
Trifluralin[g]	Treflan HFP	Caution	NA; one application between first true leaf and 6 inch stage	0.72	4.0	Causes moderate eye irritation, harmful if swallowed, potential skin sensitizer. This product contains aromatic hydrocarbon and can be extremely toxic if swallowed. This pesticide is extremely toxic to freshwater marine and estuarine fish and aquatic invertebrates. Soil incorporation required within 24 hrs of application. Crop injury warnings. Crop rotation restrictions ranging from 5 to 21 months. Confirmed multiple resistant weed biotypes.	Long-sleeved shirt, long pants, shoes plus socks, chemical-resistant gloves, protective eyewear. Do not reuse clothing heavily contaminated with this product's concentrate.
Triflusulfuron	Upbeet	Caution	60	0.008	0.08	Resistant weed biotypes; multiple MOA resistance. Need spray adjuvant added.	Long-sleeved shirt, long pants, chemical-resistant gloves, shoes plus socks.

NA indicates not applicable.

[a] PHI – Post Harvest Interval.

[b] PPE – Personal Protective Equipment.

[c] Based on recent clethodim tolerance action (67 FR 46893, Final Rule, July 17, 2002) percent-crop-treated market data necessary to refine chronic dietary exposure estimates; per label statement: concern for risks to endangered plant species.

[d] 1996 desmedipham RED: concern for Margins of Exposure (MOE) for dermal exposure to mixers and loaders; additional concern for applicator inhalation exposure to wettable-powder formulations requiring limits on application rate per acre and number of acres treated per day; low to moderate chronic risk to birds.

[e] 1999 EPTC RED ; 10x FQPA UF retained due to neurotoxic effects; developmental neurotoxicity study required; reversible Cholinesterase inhibitor; Tier 3 refinements using average residues and percent crop treated data for chronic dietary assessment; concern for risk to applicators and handlers from dermal and inhalation exposure; concern for risks to small mammals and non-target plants, including endangered species from run-off and spray drift.

[f] Based on recent sethoxydim tolerance actions (66 FR 51587, Final Rule, Oct.10, 2001), aPAD includes additional 3x FQPA UF for acute exposure to females 13+ yrs of age, due to fetal effects seen in rat developmental tox study; anticipated residues and percent-crop-treated data necessary to refine chronic exposure assessment.

[g] 1995 Trifluralin RED: concern for cancer risk to applicators, handlers and field workers; moderately to highly toxic to fish and aquatic invertebrates; chronic risk concern for birds due to evidence of egg cracking in avian study.

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Table 4-5 Potential Reduction in Risk from Use of Glyphosate Compared to Traditional Herbicides Used in US Sugar Beet Production

Active Ingredients[1]	Human Health Risk		Non-Target Species Risks					Groundwater Contamination	Total Number of Areas for Potential Risk Reduction
	Acute	Chronic	Mammals	Fish	Aquatic Invertebrates	Aquatic Plants	Avian		
Clethodim	✓	✓						✓	3
Clopyralid	✓							✓	2
Cycloate	✓		✓				✓	✓	4
Desmedipham	✓	✓						✓	3
EPTC	✓	✓	✓					✓	4
Ethofumesate	✓			✓				✓	3
Phenmedipham	✓								1
Pyrazon	✓		✓			✓	✓	✓	5
Quizalofop-p-ethyl	✓		✓					✓	3
Sethoxydim	✓	✓					✓		3
Trifluralin	✓	✓		✓	✓	✓	✓		6
Triflusulfuron	✓								1

[1] Traditional herbicides are compared to glyphosate, using the label from Roundup WeatherMAX herbicide.
✓ Indicates there is a potential for reduction in risk category by using Roundup agricultural herbicides.

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Appendix A

Willamette Valley Specialty Seed Association (WVSSA) specialty seed production isolation guidelines and Columbia basin vegetable seed field isolation standards

WVSSA Specialty Seed Production Isolation Guidelines

***Beta* species (Beets and Swiss chard)**
Must be pinned at the Beta species maps
Four Separate Groups: Sugar beets, Table beets, Fodder beets, Swiss chard

Between one O.P. and another of the same color and group	1 mile
Between Hybrid of the same color and group	1 mile
Between Hybrid and O.P. of the same color and group	2 mile
Between different colors within a group	3 mile
Between stock-seed and a Hybrid within a group	2 mile
Between stock-seed and O.P. within a group	3 mile
Between Hybrids of different groups	3 mile
Between Hybrid and O.P. of different groups	4 mile
Between GMO's and any other Beta species no closer than (And is excluded from exception to lessen this distance)	3 mile

***Brassica* species (Fall types – 9 chromosomes)**
Includes: Cabbage, Kale, Kohlrabi, Brussel Sprouts, etc.

Between O.P. of the same color and group	1 mile
Between O.P. of different color	2 mile
Between O.P. cabbage and non-heading cultivars (Savoy, Kale, Brussel Sprouts, Collards and Cauliflower)	2 mile
Between Hybrids and Hybrids and O.P. of the same color and group	2 mile
Between Hybrids and O.P. of different colors or group	3 mile
Between Hybrid cabbage and non-heading cultivars	3 mile

***Brassica* species (Spring types – 6 groups)**

1 Turnip types – 10 chromosomes (Japanese type, purple top, strap leaf, Shogoin)
2 Chinese Mustard types – 10 chromosomes (komatsuna, mizuna, mibuna, tatsoi)
3 Chinese Cabbage types – 10 chromosomes (heading, semi-heading, non-heading)
4 Pak Choi types – 10 chromosomes
5 Choi Sum types – 10 chromosomes
6 Indian Mustard types – 18 chromosomes (Florida broadleaf, southern giant curled, red mustard, Chinese mustard, leaf mustard)

SPECIAL ATTENTION MUST BE PAID TO THESE CROPS AS THERE IS A VERY WIDE RANGE OF PHENOTYPES THAT CAN CROSS. IF THERE IS ANY DOUBT, CHECK WITH THE OTHER COMPANY REP. BEFORE PINNING & PLANTING.

Between any 10 chromosome and any 18 chromosome types	Physical separation
Between O.P. of the same group	1 mile
Between O.P. of different groups	1.5 mile
Between Hybrids or Hybrids and O.P. of same group and phenotype	2 mile

Between Hybrids of different groups or phenotype	2.5 mile
Between Hybrids and O.P. of different groups or phenotype	3 mile

***Brassica* species Canola**

Must be grown under permit from Oregon Department of Agriculture. GMO type Canola or Rapeseed is not allowed to be grown between any other specialty seed crops.	3 mile
Allium cepa (Onion) Male parent used to pin hybrids	

Onion Hybrid

Between Hybrid and O.P. of different color	3 mile
Between Hybrid and O.P. of same color, different shape	2 mile
Between Hybrid and O.P. of same color, shape and type	2 mile
Between Hybrid of same color, shape and type	1 mile
Onions Open Pollinated	
Between Hybrid and O.P. of different color or shape	3 mile
Between O.P. of different color	3 mile
Between O.P. of same color, but different shape	2 mile
Between Hybrid of same color and shape	2 mile
Between O.P. of same color, type and shape	1 mile

Allium fistulosum (Bunching Onions)

Between another variety of fistulosum	1 mile

Allium porrum or Allium ampleoprasum (Leek)

Between another variety of Leek	2 mile

***Allium* other species (Chives)** no distance

***Umbelliferous* other species (Parsley, Dill, Parsnips, etc.)**

Between same types	1 mile
Between Hybrid and O.P. of similar types	2 mile
Between different types	3 mile

Rhaphanus sativus (Radish)

Between O.P. varieties of same color and or shape	1 mile
Between Hybrids or Hybrid and O.P. type	2 mile
Between Hybrid and O.P. of different colors and or shape	3 mile
Between Red globes or from White tip type	1 mile
Between Long Red from any other Red type	2 mile
Between Any Red from any other White type	3 mile
Spinacit used to pin hybrids	
Between O.P. of the same leaf shape type	1 mile
Between O.P. of different leaf shape type	3 mile
Between Hybrid and O.P. type	3 mile

Cichorium intybus **(Chicory)**
Includes: raddichio, chicory, witloof, fodder root

Between O.P. type or endiva species	1 mile
Between Hybrids or Hybrid and O.P. type	2 mile

Cichorium endiva **(Endive)**
Includes: endive, escarole, frizze

Between O.P. type or intybus species	**1 mile**

Cucumis sativus **(Cucumber)**

Types: Slicer, Pickle, White spine, Black spine, Beta alpha.

Between O.P. of the same type	1 mile
Between O.P. of different type or spine color	2 mile
Between Hybrid and O.P. type	3 mile
Between Hybrid of different type or spine color	3 mile

Cucurbita **species (Squash)**

Includes: pepo, moshchata, mixta, maxima

Between Similar types, shape and color	1 mile
Between Same or Different species	1 mile
Between another Hybrid of similar variety	1 mile
Between Hybrid and O.P. of similar type and shape	1.5 mile
Between O.P. or Hybrid of different type, shape or color	2 mile

Flowers

All Flowers need to be pinned
Between ones that cross pollinate 1 mile
Includes: Chrysanthemums, Sunflowers, Helianthus, Poppies, etc.
Multiple non-crossing flowers at one location can be pinned with one pin denoting flowers
Consult company representatives on general pinned flower locations

All other seed crops need to be pinned.

For isolation distances consult company representatives

WVSSA

Specialty Seed Production

Pinning Rules

To facilitate communication and protect the specialty seed industry in the Willamette and Tualatin Valleys of Oregon, isolation mapping procedures have been drafted and agreed upon

by the Willamette Valley Specialty Seed Association (WVSSA). The procedures and isolation distances as outlined below have been set up to ensure quality seed production of all vegetable and other specialty seed in the designated areas from potential cross pollination. The isolation control area of interest referred to as the Willamette and Tualatin Valleys includes the counties of; Multnomah, Washington, Clackamas, Yamhill, Polk, Marion, Benton, Linn, and Lane.

Maps

The association has four separate maps for the purpose of pinning and maintaining appropriate isolation distances. There are two for non-*Beta* species, and two for *Beta* species. The maps are then divided by the North and South valley isolation areas. They are established at four different locations as follows:

Non-*Beta* Species Locations

Map1 - North Valley Pinning
OSU Extension Service Marion County Phone: 503-588-5301
At: 3180 Center NE, Salem, Oregon 97301 Room 1361

Map 2 - South Valley Pinning
OSU Extension Service Linn County Phone: 541-967-3871
At: 104 4th Ave SW, Albany, Oregon 97321 Room 102

***Beta* Species Locations**

Map 3 - North Valley Pinning
West Coast Beet Seed Phone: 503-393-4600
At: 2380 Claxter Rd NE, Salem, Oregon 97303.

Map 4 - South Valley Pinning
Betaseed, Inc. Phone: 541-926-0161
At: 34303 Hwy 99 E, Tangent, Oregon 97389

The non-*Beta* types are to be pinned at the non-*Beta* locations in respect to their valley area.
The North map is for pinning isolations: Including and North of Township 9 South.
The South map is for pinning isolations: Including and South of Township 9 South.
Fields located within Township 9 S. must be pinned on both North and South maps.

The *Beta* types are to be pinned at the *Beta* locations in respect to their valley area.
The North map is for pinning isolations: Including and North of Township 11 South.
The South map is for pinning isolations: Including and South of Township 12 South.

Pinning Procedures

To identify production fields for location on the map, pins and flags will be used to mark the isolation. On the non-*Beta* maps, different color flags are used to separate the major crop types.

1. Must have approved pinning rights and abide by the guidelines of the WVSSA.
2. Observe the dates covered under the priority pinning.
3. Check for acceptable isolation distance on the maps.
4. Use proper flag to pin the field.

Written on each flag will be: Party name, Crop type, Hybrid or O.P., Legal location.

5. Fill out pinning card at time of pinning.

6. At non-*Beta* maps, have Extension personal date stamp card and place in lock box.
7. At *Beta* maps, pin as set up at each location, date stamp card and place in lock box.
8. Contact any companies involved if isolation guidelines are in question.

Pins will be placed as close to the center of the field to be planted as possible. This will be done to facilitate proper isolation distances to other fields. The isolation is not valid if that isolation is pinned incorrectly.

The map cannot be pinned until an established agreement has been made with the grower for planting the crop. The map cannot be pinned on a speculative basis in order to reserve isolation. Upon cancellation of an intended production prior to planting the pin must be removed within 5 days. Upon abandonment of an established production, the pin must be marked failed. A penalty may be assessed of $50.00 if in violation and payment is required to remain a member in good standing.

Pinning Priority
The WVSSA allows the grower to hold the right to the isolation in his perspective farming area for the following year, to produce the same crop within a one-mile radius to the prior year's isolation. The grower maintains the right to elect the contracting company. The isolation right, known as a prior year's priority can only be held for the specific grower until the dates specified below.

A prior year's priority is only valid until the following dates:
For non-*Beta* species: Annuals - March 1st Biennials - August 1st
For *Beta* species: Transplants - February 1st Direct seeded - August 1st
After these dates, all isolations are available on a first come basis.

Pinning Rights:
The contracting company or responsible seed representative, who is a member of the WVSSA, may do the pinning. The intent is for the contracting company or responsible seed representative to do the pinning. The representative appointed by a company may also do the pinning if the company is a member of the WVSSA. Oregon State University is considered here as a non-due paying member that has pinning privileges.

The contracting company or responsible seed representative with a grower agreement acts as the grower's appointed representative in establishing the isolation. Individual growers are to allow their contracting company or responsible seed representative who is a member of the WVSSA, to establish the isolation. Growers are allowed to be members of the WVSSA and would be considered as a responsible seed representative and as a member would be allowed to pin isolations for their farms under their own agreements. The contracting company or responsible seed representative agrees to abide by the pinning and isolation guidelines of the WVSSA.

New pinning parties need to contact an officer of the WVSSA for eligibility approval a membership is required prior to pinning. The responsible party may be required to have membership approval by the association. The association may elect to appoint a representative to meet with the new parties at the appropriate isolation map to clarify pinning practices.

Membership and Pinning Fees:
The member or responsible party for the seed is subject to fees as established by the WVSSA. Fees are inclusive of the WVSSA annual membership dues of $150.00 per year, or a Homestead membership fee of $5.00 per year. The pinning fees are; $10.00 per OP crop, $25.00 per Hybrid crop, and $25.00 Multi-crop fee. Annual dues for the current year and pinning fees for the prior year's pinning are assessed at the beginning of each year. If dues and pinning fees are not received, pinning rights may be revoked.

A multi-crop fee may apply when producing multiple crop species of an OP in one location, and one acre or less. Only one per member is allowed and is intended for research farms, and small commercial farms used for seed production. The multi-crop fee is not a pin, crop pins must be used to pin different species, and multi-crop must be designated on each card turned in.

A Homestead membership fee and no pinning fees may apply for a Homestead non-voting member when producing in one location non commercial OP seed crops. Intended for the seed saver this member is not eligible for the pinning priority and is required to follow WVSSA rules and to be accompanied by a designated appointee when pinning the map. Crop pins must be used to pin different species, and Homestead must be designated on each card turned in.

Exceptions Agreements
There are two exception agreements, the Isolation Distance Encroachment, and the One Year Isolation Deferral. The Encroachment exception applies to an established crop isolation where one company agrees to allow another company to produce a like crop under less than the set isolation distance. The deferral applies to an established crop isolation where one grower and company agrees to allow another grower and company to produce a like crop for one year, and the established grower retains the isolation priority.
The parties involved prior to planting a specific crop must agree upon any exception to the established isolation for the specific crop year. The exception agreement needs to be in writing annually and to include the right to the isolation the following year. There are exception agreement forms available for this use. All parties must agree and all other WVSSA isolation rules must be followed.

Securing Isolations
At all maps a system of cards and a lock box will be used and parties using the maps must follow the WVSSA rules. Fields must be currently identified for both the past and present crop year. Failure to pull pins will result in a penalty under the WVSSA.

At the non-*Beta* maps, at the time of opening the lock box, a representative from two different companies of the WVSSA, in addition to an Extension Agent, are required to be present. The lock box will be emptied annually when the prior crop year's map is cleared.

At the *Beta* maps, the procedures for pinning must be followed at each location. The cards will be date stamped, except not by an Extension Agent, and placed in lock box. The lock box can only be opened and will be emptied annually by two members of the WVSSA.

The purpose of the lock box is: 1.To use as the archive and formal record of posting of pins. 2. To review established pinning priority rights. 3. To be used for pinning dispute resolutions. Any discrepancies over pinning locations will be solved through the cards. The cards will be used for accuracy of pinning and in case of arbitration. Pinning cards will be archived indefinitely.

Arbitration
Should all precautions fail in preventing potential cross-pollination problems between seed companies or responsible seed representative, and or growers, the WVSSA suggests the following system or arbitration: Fields not pinned will be considered at fault in event of arbitration. If the parties agree to arbitration by the three-person committee, they agree to abide by the committee's recommendation. The two contesting seed companies or responsible seed representative, in consultation with their growers, each chooses an outside field representative from the WVSSA. The arbitrators, A and B, are suggested to a neutral facilitator who notifies them of their role. They do not know whom they represent and together choose a third committeeman. Arbitrators A, B and C agree to hear the facts of each seed company. Maximum would be two representatives on each side of the issue. After both parties present the facts, only the arbitration committee, A, B and C, remain in the room to discuss the facts fully. They agree to a solution before leaving the room and the chairman will deliver the recommendation immediately to both parties.

Columbia Basin Vegetable Seed Field Isolation Dates[1]

With a valid "release"[2], vegetable seed company representatives may reserve fields for vegetable seed production as follows:

Annuals and carryover onions[3]	February 1 or closest weekday thereafter
Onion and other biennials (except carrots)	March 1 or closest weekday thereafter
Carrots and fall planted annuals	June 1 or closest weekday thereafter

[1] These dates for crops are as per agreement at the January 21, 2005 meeting of the Columbia Basin Vegetable Seed Field Representatives Association.

[2] A release must include the production company, crop, and crop year for placement in Columbia Basin production and either the number of fields or number of acres.

[3] Carryover onion crops may be repined with priority between February 1 and March 1, after which priority is lost.

Columbia Basin Vegetable Seed Field Isolation Standards*

All genetically modified crops will be designated as GMO.

CARROT FAMILY (*Apiaceae*)

CARROT (Pinned by Group and Type)

Groups: Hybrid and Open Pollinated

Types:
Chantenay (Danvers, Red Cored, Royal, etc.)
American Market (Imperator, etc.)
Early (Amsterdam, Baby Carrot, etc.)
Medium (Nantes, etc.)
Late (Flakkee, Berticum, etc.)
Round and Odd Shapes (Paris Forcing, etc.)
Oriental (Usually short Chantenay shape)

Distance: Between Hybrids.....2 miles
Between Hybrids and Open Pollinated.....2 miles ♦
Between Types within Groups.....1 mile
Between Varieties of same Type.....½ mile
Between same Varieties for different companies.....¼ mile

Off-color carrots should be grown outside main production area and pinned by color with a minimum isolation distance of 5 miles from other colors.

♦ Note: A 3 mile isolation will be permitted between Hybrid and Open Pollinated carrots where requested.

PARSLEY Between all Types and Varieties.....1 mile

CORIANDER (cilantro or Chinese parsley) Between all Types and Varieties 1 mile

MUSTARD FAMILY (*Cruciferae*)

RADISH (Pinned by Group and/or Type...Understood to be O.P. unless otherwise noted)

Groups: Hybrid and Open Pollinated

Types:
Round Red
Round Red Forcing
Crimson Giant
Round Red White Tip
Half Long White Tip
Long Red
Icicle (and related forms)
Round White
Purple
Black
Other

* Standards as of March 1, 2006 as agreed upon by the Columbia Basin Seed Field Representatives Association. Revised 03/06.

RADISH **Cont'd.**

Daikon (assumed to be white rooting type unless specified)
Daikon Sprouting
Daikon, Red
Daikon, Green

Distance: .....Between Hybrid and Open Pollinated.....2 miles
Between any red Type and any white type.....2 miles
Between any round white, icicle Type, purple, black, or any Daikon Types and any other radish.....2 miles
Between Round Red, Crimson Giant, Long Red, round White Tip, and Half Long White Tip.....1 mile
Between Daikon, Sprouting, and any other Daikon of same color 1 mile
Between Round Red and Round Red Forcing.....½ mile
Between Round Red Varieties (unless negotiated between companies) ½ mile

RAPESEED

Canola and other Oilseed Types .....3 miles

Genetically modified Canola and other Oilseed Types will be designated as GMO

OTHER CRUCIFERS (Pinned by crop name and chromosome number)

All Groups or Types .....2 miles

ONION FAMILY (*Alliaceae*)

ONION (Pinned by Group and Type)

(*Allium cepa*)

Groups: Hybrid and Open Pollinated

Hybrid: (Should be posted as male parent)
From Hybrid or O.P. of different color.....3 miles
From Hybrid or O.P. of same color, but different shape (i.e. Globe vs. Flat) 2 miles
From O.P. of same color and shape.....2 miles
From Hybrid of same color, but different shape.....2 miles
From Hybrid of same color, shape, and Type (i.e. Yellow Spanish vs. Yellow Spanish) 1 mile
From *Allium fistulosum*, Chives, or Leek.....None

Open Pollinated:
From Hybrid or O.P. of different color or shape.....3 miles
From O.P. of same color, but different shape (i.e. Yellow Globe vs. Yellow Ebenezer) 2 miles
From Hybrid of same color and shape.....2 miles

From O.P. of same color, but different Type (i.e. Yellow Spanish vs. Yellow Globe) 1 ½ miles
From O.P. of same color, Type, and shape (i.e. Yellow Spanish vs. Yellow Spanish) 1 mile
From *Allium fistulosum*, Chives, or Leek.....None

(*Allium fistulosum*)

Open Pollinated:
From *Allium cepa*, Chives, or Leek.....None
From another variety of *Allium fistulosum* (i.e. Tokyo Long White vs. He-Shi-Ko) 1 mile

ONION Cont'd.

Hybrid:
From any O.P. or Hybrid *A. fistulosum*.....2 miles

(*Allium cepa-fistulosum* cross) CFC
tetraploid double chromosome

Open Pollinated:
From *Allium cepa* or *Allium fistulosum* of the same color.....None
From *Allium cepa* or *Allium fistulosum* of a different color.....None
From another Variety of CFC of the same color.....1 mile
From another Variety of CFC of a different color.....3 miles

CHIVES

From *Allium cepa, Allium fistulosum,* or Leek.....None
From another Variety of chives.....1 mile

LEEK

From *Allium cepa, Allium fistulosum*, Chives.....None
From another Variety of Leek.....1 mile

GOOSEFOOT FAMILY (*Chenopodiaceae*)

BEETS

Between all Beets, Swiss Chard, and Mangels.....3 miles

Sugar Beet Types:
Diploid
Tetraploid

From Sugar Beets of the same or different Type.....2 miles

Genetically modified Sugar Beets will be designated as GMO

Appendix B

West Coast Beet Seed Company protocol for genetically modified (GM) seed production and GM grower guidelines

PROTOCOL FOR GENETICALLY MODIFIED (GM) SEED PRODUCTION
(Direct-Seeded, Transplants, Nurseries, Plots)

DETECTION

1. West Coast Beet Seed Company will request the help of Members to set up assay for QC (detection) of Roundup Ready (RR) gene in sugar beet seed lots.

2. West Coast Beet Seed Company will, from time-to-time, add additional assay of QC (detection) for other events as needed.

3. West Coast Beet Seed Company will conduct the assay for QC of RR on all RR seed lots. For the protection of West Coast Beet Seed Company and to learn if the processes are meeting the desirable criteria, random testing of non-GMO seed lots will be conducted. West Coast Beet Seed Company may consider using zones, based on distances from the GM source, for determining this random testing. Members have the option of requesting all of their lots be tested. Members have the option of requesting this information in written form.

4. The shipping document will indicate that the shipment contains GM seed.

5. West Coast Beet Seed Company assigns a lot number to the potential seed lot prior to the item being planted. This number stays with the seed lot and becomes a permanent record for this lot.

6. West Coast Beet Seed Company will inform members of all past events grown so members can test their seed lots.

ISOLATION

1. West Coast Beet Seed Company's goal is to develop an agreement with sugar beet, chard, and red beet seed companies to avoid cross contamination and to develop a program to inform each other as to the locations of present and past GM and non-GM seed productions.

2. Within a three mile radius of any RR field, West Coast Beet Seed Company will monitor for any volunteers in any fields used for sugar beet production, over a minimum of the past five years or until no volunteers are observed.

3. West Coast Beet Seed Company will monitor GM fields for a minimum of five years or until no volunteers are present. This will protect chard, red beet, and sugar beet seed production in the area. The removal of the volunteers will be done under the supervision of West Coast Beet Seed Company representatives and recorded in a log book. The costs will be shared between West Coast Beet Seed Company and the grower.

4. West Coast Beet Seed Company will maintain a minimum three-mile isolation between GM and non-GM sugar beet production. The isolation between GM pollinators/productions where the same event is present will be a minimum of one mile.

The isolation between sugar beet, chard, and red beet will be a minimum of three miles until an agreement can be reached with the other companies.

STOCK SEED/STECKLINGS/SEED TAGS

1. West Coast Beet Seed Company has adopted an orange color tagging system to visually identify GM material (GM stock seed, GM stecklings, GM seed in tote boxes, cotton or burlap bags, GM seed samples, and member's shipping containers). The orange colored tags identify the product as GM and it is to be treated according to the protocol. In respect to each Member company's policies, GM material going to or coming from West Coast Beet Seed Company will be tagged with the preferred identification of that member company.

Member Requirements:

1. Prior to GM stock seed being shipped to West Coast Beet Seed Company, the members will send a document (Movement Traceability Form) identifying the stock seed items (I. D. code number, etc.) that will be GM.

2. Each GM stock seed bag arriving from members will already contain an orange tag marked in writing, stating it is GM seed. The stock seed bags can also contain the Member company's GM identifying colored tag, code, symbol, etc.

    A. If stock seed arrives and there are any inconsistencies in the paperwork, orange tagging, non-orange tagging, or any other inconsistency of labeling, the warehouse personnel will notify the Manager and the seed will be put on hold until the member clears the issue and backs it up with the proper documents. The seed will be stored on a separate pallet in the GM portion of the warehouse. The pallet will be marked clearly in a manner to prevent it from being prepared for planting.

West Coast Beet Seed Company's Requirements:

1. The GM stock seed will be stored separately from the conventional stock seed. The area will be in the main building, along the east wall, near the Warehouse Manager's office and will be identified in a clear manner.

    A. Non-GM seed will be stored in the northwest warehouse, of the main building, by the main dock.

2. The GM stock seed will be prepared for grower disbursement in the main building, along the east wall, near the Warehouse Manager's office.

    A. A sample of the GM stock seed will be held in a separate area of the warehouse for five years. This sample will be labeled with the orange colored tag and the preferred identification of the member company.

3. Once the GM stock seed is prepared for the grower, it will be labeled with an orange tag indicating to the grower that they have in their possession GM seed.

4. Accompanying the GM stock seed will be a written document declaring that the seed is GM.

5. The stock seed for GM and non-GM productions will not be transported to the growers in the same vehicle at the same time. The field staff will be trained properly at least once a year in the handling of GM seed and all seed movement will be documented.

6. The field supervisors are responsible for collecting the remaining stock seed from the growers immediately after planting. The Warehouse Manager will log in the stock seed. When GM stock seed is returned from the growers after planting, sealed bags will be returned to the member. Opened bags will be incinerated at the County garbage burning facility to prevent use of potentially grower-contaminated seed.

   The Member will be informed, in writing, of the amount, location, and date destroyed. The Member also will be informed, in writing, as to amount being returned to them.

GM NURSERY

1. The GM nursery will be kept separate from the conventional nursery.

   A. The owner of the nursery ground will have given West Coast Beet Seed Company written permission to plant GM stock seed.

2. The GM stock seed for the nursery will be handled the same as any other GM stock seed (information from member, orange tag, stored in separate area, etc.) (see above "STOCK SEED/STECKLINGS/SEED TAGS").

3. The digging equipment will be completely clean of any stecklings before entering or leaving the GM nursery. West Coast supervisors will sign a document stating they have personally inspected the equipment after cleaning and found it to be free from any stecklings.

4. All GM stecklings will be stored in sacks that are marked with a GM orange tag. The stecklings will be stored in a cooler or warehouse separate from non-GM stecklings.

5. There will be a separate GM observation nursery and it will be isolated in the area where GM productions of the same event(s) are being grown.

GROWING THE CROP
(Planters, tillers/flail, sprayers, separators, male removal, swathers, combines, tote boxes, hauling, tarps/lids)

Any equipment (planter, transplanter, sprayer, flail, tiller, tractor, irrigation equipment, vehicle, separator, clipper, swather, combine, tote box, post-harvest tilling equipment, seed cleaning equipment, or any other equipment) must be monitored, treated, cleaned, and the process documented, according to West Coast Beet Seed Company's policies.

The intent is to prevent seed, pollen, or stecklings from being transferred out of the area of control or transferred to where they could contaminate other Beta species productions (details of the methods are found in other parts of this protocol).

1. West Coast Beet Seed Company will use only designated totes for GM seed harvest by growers. Phase one will be metal totes only. Phase two will be metal totes and designated wood totes.

   A. During transportation, the totes will be covered with a West Coast Beet Seed Company approved high-quality tarp or high-quality lid.

2. Trucks transporting commercial GM seed will not carry non-GM seed on the same load.

3. Growers will not be allowed to transfer bulk seed to totes at third party locations (i.e. grain elevators) unless, in the opinion of West Coast Beet Seed Company and upon approval of the member company(ies), the seed can be transferred in a manner that would allow complete and easy transfer without contamination of equipment or surrounding area. To avoid spillage, growers must not transfer seed from one tote to another.

4. Any pesticide application made during the flowering period needs to be done by aerial applications. If aerial application is not possible, then West Coast Beet Seed Company will use its operator and modified equipment to spray. If the grower has high clearance spray equipment that does not leave his farm, then we can consider using this equipment.

   The Member will be notified in advance as to which productions West Coast Beet Seed Company will use its equipment for spraying after flowering begins.

5. When the GM production is in bloom, any person who enters the field (grower or their workers if they would be going to any other Beta species production, West Coast Beet Company staff or temporary workers, Member or their representatives), will wear disposable coveralls. They are to be removed and disposed of after each use. The disposable clothing will be stored in a separate, closed container so that live pollen cannot escape the area or be transferred into another field.

   A. Clean, disposable, coveralls will be kept in a closed container prior to use. These coveralls will be furnished at West Coast Beet Seed Company's expense. West Coast Beet Seed Company's field supervisor is responsible for the disbursement of the disposable clothes, for having people wear them, for training people how to dispose of them, and finally to control the good use of them.

SEED CLEANING, STORAGE, SHIPPING CONTAINERS, AND SCREENINGS DISPOSAL

1. GM seed will be delivered in designated totes. The totes will be affixed with all appropriate tags, including a GM orange tag which will designate it as containing GM seed.

A. These totes will be stored in a designated portion of the warehouse(s) physically separated from non-GM seed. The seed will also be unloaded in a separate area and only GM designated and marked equipment (brooms, conveyors, etc.) will be used for GM seed.

B. The field-run samples also will be affixed with a GM orange tag and these samples will be stored separately from non-GM samples. This requirement will be added to the scale house procedures and policies. Scale house personnel will be trained in these procedures, each year, prior to seed delivery.

2. West Coast Beet Seed Company will, in the beginning years, utilize one or two of the cleaning lines to process GM seed. The GM seed will be cleaned at the end of the processing period to avoid potential problems.

A. The Company shall not clean conventional and GM seed simultaneously, except in an emergency. In the event of an emergency and the Company must clean conventional and GM seed simultaneously, a physical barrier, such as a plastic wall, shall be put in place to avoid contamination.

B. All cleaning equipment will be thoroughly cleaned prior to and after cleaning GM seed. This will ensure that all GM seed has been removed from equipment prior to any non-GM seed being introduced after that point. (Detailed instructions of cleaning the equipment are already in place).

C. A permanent log is kept for the cleaning sequence.

3. West Coast Beet Seed Company will draw a representative clean seed sample and tag it with a GM orange tag.

A. Part of this sample will be tagged with a GM orange tag and sent to Agri Seed Testing for germination and purity testing. Agri Seed Testing will be informed that the seed is GM. Agri Seed Testing holds their samples for three (3) years and then will destroy them by incineration in the County garbage burning facility.

B. Part of the sample will be tested via the QC assay method for the event(s). (This will be expanded to include how this information will be disseminated). See DETECTION category number 3, paragraph 1 above.

C. A minimum of one (1) pound will be stored in a separate area for five years labeled with an orange tag and the preferred identification of the member company.

D. Members at their request will be sent their requested amount of properly labeled, clean seed samples.

4. Screenings from GM production will be delivered to either the pellet mill or composting facility.

A. West Coast Beet Seed Company will check yearly with the pellet mill company to see if the feed pellets will be sold where GM is presently not allowed (Europe)[44]. West Coast Beet Seed Company will keep members informed on the result of this discussion.

B. In the future, regulated screenings can be delivered to a landfill if required.

5. Shipping of GM seed to members will be in new containers (boxes, poly tote bags, etc.). The containers will be affixed with a GM orange tag and the preferred identification of the member company. Shipping containers (cardboard boxes and poly bags), because they are known to hold some seed in crevices, will not be allowed to be reused at this time. Therefore, West Coast Beet Seed Company would prohibit GM shipping containers from being returned for reuse.

A. The paperwork that goes with the seed will indicate seed in truck contains GM seed.

B. For the protection of West Coast Beet Seed Company and its members, GM and non-GM seed will not be shipped on the same truckload to the Members' facilities.

GM GROWER GUIDELINES

The policy for the grower guidelines will include the following revised requirements:

1. The policy will be a part of the Grower Contract.

2. The grower will have only a GM production (of one event) or a non-GM production; not both in a given year. This applies to growers who grow only for West Coast Beet Seed Company and to those growers who grow for both West Coast Beet Seed Company and another sugar beet seed company.

A. The grower will not raise a GM crop and a chard or red beet seed production in the same year.

3. The grower will use precaution in the field to eliminate seed from remaining loose on the transport deck prior to leaving the field.

A. Clean off deck of loose seed prior to leaving field. This is part of the protocol that will be reviewed with the Grower.

B. (West Coast Beet Seed Company will work on designing a method to prevent seed from falling between boxes. We may also promote bulk hauling to the plant and transfer to boxes).

4. Grower cannot use/share any equipment that might be used in a non-GM sugar beet, chard, or red beet seed production in the same growing year.

[44] Import of food and feed products derived from Roundup Ready sugar beet event H7-1 was approved by the European Union in October, 2007.

5. Grower cannot use same combine to combine GM sugar beet, non-GM sugar beet, chard, or red beet seed in same year.

   A. The grower will combine 200 acres of another crop between combining any beta species.

6. We want a rotation of five crop plantings since the last beta species was grown on the field for seed.

7. Grower training on all aspects of GM growing handling will be conducted by management and field staff.

RECORDKEEPING

1. West Coast Beet Seed Company will continue to maintain a permanent GPS computerized mapping system to record all productions including year, item number, and lot number.

2. West Coast Beet Seed Company maintains a yearly and ongoing computerized log where all important activities of the production are recorded (Crop Tracker). The Grower may collect information, but the final responsibility for this data collection is the field supervisor.

3. Crop histories of herbicide and crop are collected each year prior to planting.

4. West Coast Beet Seed Company will develop a method for tracking all movement of GM seed from the time West Coast Beet Seed Company receives the stock seed, to the final processing and shipment to the member. This information will be communicated to the members upon request. The members may also request additional information when necessary for stewardship of the GM crops.

INSPECTION

New disposable clothing will be used by West Coast personnel, grower, custom contractor, and member company personnel when entering the field when pollen is present. After each use, the clothing will be discarded into a sealed container and then disposed of in customary container (garbage can, dump box).

RISK ANALYSIS

The protocol needs to be continually reviewed. During the review and handling of the crop, new areas of concern may become evident. When this occurs, the concern must be addressed and solutions implemented. Final approval of any changes to the contracts must be approved by the Contract Committee and recommended by the committee to the Board of Directors in a timely fashion.

TRAINING

1. All West Coast Beet Seed Company employees will be trained in all areas of the protocol. Date, time, personnel attending, type of training and instructor should be recorded for all training sessions and appropriately filed.

   A. West Coast will train personnel on these policies and procedures. Written training documents will be reviewed and approved by the board.

2. West Coast Beet Seed Company employees that deal with specific areas will have extensive and continual training in the specific area.

3. Both West Coast Beet Seed Company growers and personnel will be trained in the relevant areas of the protocol. Date, time, attendees, type of training and instruction should be recorded for all training sessions and appropriately filed.

4. Part of the training will include the following West Coast Beet Seed Company policy: Operators discovering evidence of spillage or GM seed out of place immediately will inform their supervisor, the head of department, and the West Coast Beet Seed Company Manager. At first evidence of the problem, appropriate action will be taken to halt the release of any additional seed, pollen, or plant material. The problem will be evaluated immediately to prevent a reoccurrence. Appropriate individuals or companies will be informed of the situation.

GM Grower Guidelines

I. The following are guidelines to which all West Coast Beet Seed Company commercial growers are required to adhere in the contract production of genetically modified (GM) sugar beet seed. If questions arise with this production, contact West Coast Beet Seed Company's fieldmen for clarification or explanation.

   Direct seeded and transplant productions will adhere to the guidelines, except with reference to transplanting. West Coast Beet Seed Company will perform the transplanting in winter/spring.

   A. **Field Selection:** Genetic purity is of the utmost concern with this type of seed production. Field selection encompasses many characteristics, but the main features that are necessary include fields with required isolation of at least three miles from non-GM productions and one mile between GM pollinators/productions, the least chance of having volunteer beets from previous productions, good fertility, favorable location (not likely to flood), available for timely plantings into pre-irrigated conditions, good irrigation systems, and good water availability. At a minimum, a rotation of five crops since the last beta species were grown for seed is required.

   B. **Planting:** Stock seed will carry an orange tag to indicate GM. The goal is to plant into fertilized, pH adjusted as necessary, and pre-irrigated fields to ensure timely establishment of desired stands. It is desirable to have a population of 4-5 beets per foot of row in all lines for direct-seeded production.

Stock seed normally is limited in supply, so close monitoring of seed drop is essential to establishing uniform stands across the entire planting. Stock seed will be stored safely to ensure no seed is lost inadvertently or released into the environment inadvertently. All unused stock seed will be returned to company personnel in a timely manner.

Planters must be monitored both before and after planting to ensure that the proper seed is being planted. After planting, the planter and the tractor need to be cleaned in the field to remove 100% of the seed prior to moving the planter to another location. The intent is to prevent seed from being transferred out of the area of control or transferred to where it could contaminate other beta species productions.

C. **Irrigation:** Fall irrigation of direct-seeded production should start after planting, as necessary, and continue through emergence and stand establishment.
Spring irrigation of direct seeded and transplant production should begin as the soil moisture drops and crop growth requires supplemental moisture. Spring irrigation should continue as the crop grows and matures to the point that additional moisture is no longer beneficial to production of a quality crop.

West Coast Beet Seed Company personnel will determine the timing of the last irrigation.

Irrigation equipment will be cleaned of any live GM pollen before leaving the field. If this is not possible, then irrigation equipment should be left by the field for 24 hours before moving to another location.

D. **Disposable Clothing Requirements:** When the GM production is in bloom, any person who enters the field, and who may enter another Beta species production that same day, will wear disposable coveralls. These will be furnished at West Coast's expense and they are to be removed and disposed of after each use. This will prevent live pollen from being transferred to another field.

E. **Care of the Crop:** The crop will be cared for in the best interest of obtaining a high quality and high-yielding production. Management practices of individual fields vary and shall be approved by West Coast Beet Seed Company's field staff. Recommendations by Company representatives will be carried out in a timely and efficient manner.

1. Any pesticide application made during the flowering period needs to be done by aerial applications. If aerial application is not possible, then West Coast Beet Seed Company will use its operator and modified equipment to spray. If the grower has high clearance spray equipment that does not leave his farm, then we can consider using this equipment.

F. **Pollinator Removal:** Removal of pollinator in a timely manner is very important to production of high quality seed. Pollinator destruction will be completed within the time frame agreed upon with West Coast Beet Seed Company representatives. West Coast Beet Seed Company representatives will approve destruction methods and equipment. Equipment **will not** be used in another

beet field until thoroughly cleaned of pollen and/or seed and inspected by West Coast Beet Seed Company field supervisor or his representative.

1. Any equipment (flail, tiller, separator, tractor, vehicle) must be cleaned to kill all live pollen before leaving the field according to West Coast Beet Seed Company's policies.

   The intent is to prevent pollen from being transferred out of the area of control or transferred to where it could contaminate other Beta species productions.

G. **Swathing:** Swathing will be done in a timely manner as directed by West Coast Beet Seed Company representatives. Swathers will be inspected by West Coast Beet Seed Company's field supervisor for cleanliness prior to and after cutting. Swathers will be cleaned in the field after swathing to ensure that no seed is released into any adjacent field or area.

H. **Combining:** West Coast Beet Seed Company will approve the cleanliness of the growers combine. Before use, the combine must have threshed at least 200 acres of another crop since it was used last to combine any other Beta species. Approval for grower combine usage will be determined on a case-by-case basis and will depend on previous crops combined and acreage.

Combines must be cleaned before they leave the field to ensure no seed is moved into adjacent areas. Combined seed will be placed in designated tote boxes within the confines of the existing field. Grower will clean off the truck deck in the field to ensure seed is not spilled during transport. West Coast Beet Seed Company's supervisor will approve the cleanliness of the grower's combine before leaving the field.

I. **Bulk Seed:** Growers will not be allowed to transfer bulk seed to totes at third party locations (i.e. grain elevators) unless, upon approval of West Coast Beet Seed Company, the seed can be transferred in a manner that would allow complete and easy transfer without contamination of equipment or surrounding area. To avoid spillage, growers must not transfer seed from one tote to another.

J. **Hauling Seed:** All loads of seed shall be covered with West Coast Beet Seed Company approved, high-quality tarps and/or sealed with lids so no seed can be lost during transport. GM and non-GM seed **will not** be hauled simultaneously on the same truck.

K. **Post-Harvest Field Management:** Fields will be shallow tilled after harvest to a depth of not more than 3". To promote sprouting of the shattered seed, full irrigation is required, unless a West Coast Beet Seed Company representative determines adequate rainfall has occurred to promote the required sprouting. Fields will not be fall plowed for any reason. Control of sprouted seed is essential to prevent any pollen release and seed formation in future crops.

All tractors and tillage equipment must be monitored and cleaned according to West Coast Beet Seed Company's policies before leaving the field.

The intent is to prevent seed from being transferred out of the area of control or transferred to where it could contaminate other Beta species productions.

L. Fields will be inspected by West Coast Beet Seed Company for a minimum of five years or until no volunteers are noted.

M. All of these actions will be recorded at West Coast Beet Seed Company in order to establish a record of adherence to GM policy, whether the actions were taken by the grower, the company, or by both in a shared responsibility.

Appendix C

International Seed Federation Code of Conduct



CODE OF CONDUCT
(adopted by the ISF Sugar and Fodder Beet Commission)

Principles of quality assurance in beet seed production.
(Final version of 22 October 2007)

Summary

The principles and measures highlighted in this paper aims to the adventitious presence of GM[45] beet seed in conventional sugar beet and fodder beet, as well as the adventitious presence of other GMOs[46] in GM sugar beet and fodder beet seed. The adventitious presence of GMOs can only be minimized but not totally excluded because seed production occurs in open fields under natural conditions. There is a strong necessity for practicable rules and regulations governing a high level of purity for seed of conventional varieties relating to adventitious presence of GMOs and for seed of GM varieties relating to adventitious presence of other GMOs.

1. Objective

The objective of this industry position paper for the quality assurance of sugar beet and fodder beet (hereinafter referred to as "beet seed") is to describe the measures the seed industry has taken to minimize the likelihood of adventitious presence of GM beet seed in conventional seed or adventitious presence of different GMOs in GM beet seed. The Industry recommends to apply the same measures to table beet and/or Swiss chard seed production[3].

This objective is accomplished by implementing guidelines and operating procedures (preventive measures) covering every step from the stage of R&D activities up to delivery of commercial beet seed to the customer. In addition to these measures, actions are undertaken to control the various steps of this process.

2. Deregulation of GM beet events

The status of deregulation of GM sugar beet events varies according to territories. Similarly, requirements set up by regulators may vary by country. Therefore principles adopted by the industry must reflect these regional differences.

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[45] GM: Genetically modified
[46] GMO: Genetically modified organism
This code of conduct has up to now been agreed upon by the following companies: Danisco Seed, Dieckmann GmbH & Co. KG, Fr. Strube Saatzucht GmbH & Co. KG, Maison Florimond Desprez S.A.S., KWS SAAT AG, SESVanderHave, Syngenta Seeds and their affiliated companies. It is open for adoption by other seed companies producing sugar and/or fodder beet seeds.

2.1. USA

There are three GM sugar beet events which have been deregulated in the USA. One of the three events is commercialized since 2007.

2.2. Europe

No GM beet events are deregulated at this moment in Europe. As of today no commercialization of GM beet seed can take place in Europe. There is one sugar beet event undergoing the European deregulation process. This process has not been finalized. Similarly there is one fodder beet event undergoing deregulation but the process is still in progress.

2.3. Other territories in the world

There is one sugar beet event undergoing a deregulation process in certain countries.

3. Adventitious presence of GM beet seed

3.1. Adventitious presence in conventional seed

Adventitious presence of GM sugar beet seed in conventional beet seed cannot be totally excluded. As of today, there are no official thresholds governing the adventitious presence of GM seed in conventional seed in Europe. There is an urgent need for such a threshold to be in place in Europe due to the market introduction of the first GM sugar beet in the US. Thresholds will vary and some territories or countries may not regulate adventitious presence.

Adventitious presence of GM seed in conventional seed would result from the presence of GM seed or GM plants in other beet seed production at some stage of seed production or processing.

Three possible main sources of adventitious presence of GM seed in conventional seed productions are identified:

- Spread of GM pollen to multiplications of conventional seed.
- Unintentional mixing-up of plants during transplanting.
- Unintended traces of GM seed during harvest, transport, processing or storage.

Quality assurance systems have been implemented to address the issues posed by the adventitious presence. These consist in preventive measures and testing procedures for adventitious presence. They are presented in section 5.

3.2. Adventitious presence in GM seed

Adventitious presence of unintended GM seed in GM seed production would result from the presence of GM seed of another event in a production of a given event at some stage of seed production or processing of GM seed.

Similar measures as above in point (3.1) are addressing this case.

4. Pre-commercial and commercial production of GM beet seed

4.1. Europe

There are currently no pre-commercial or commercial productions of GM beet seed in Europe.

Until now, production of GM beet seed in Europe is limited to R&D[47] activities only.

Quality assurance measures that would be taken in the future for commercial seed production in Europe will be focused on the separation of GM seed and conventional seed during the whole production procedure (e.g. multiplication and processing steps).

In addition to this, tests for adventitious presence and traces of GM beet seed in commercial beet seed lots are performed.

4.2. USA

There are commercial productions of GM beet seed of one deregulated event in the USA.

Quality assurance systems to prevent adventitious presence and traces of GM seed as presented in the data sheet of the Annex have been implemented by the seed industry.
These measures are focused on the separation of GM seed and conventional seed during the whole production procedure (e.g. multiplication and processing steps).

In addition to this, tests for adventitious presence of GM seed in the GM commercial seed lots were implemented (this refers to traces of another event in a GM seed production based on an intended event).

5. Principles for preventive measures and testing procedures for adventitious presence in R&D, in conventional and in GM beet seed production

This section describes main measures (preventive measures and testing procedures) to ensure a high level of purity for beet seed regarding AP[48] of GM. Three base cases cover all situations encountered either as producer of conventional seed or as producer of GM seed.

The guidelines for preventive and control measures have thus been divided into three parts:

1. R&D activities related to GM seed (all stages of the seed development up to the basic seed production) – Data sheet in Annex 1
2. Production of conventional seed for commercialization – Data sheet in Annex 2
3. Production of GM seed for commercialization – Data sheet in Annex 3

The following sections outline general preventive and control measures to ensure a high level of purity regarding AP for conventional seed and/or GM seed.

5.1 Preventive measures

[47] R&D: Research and development
[48] AP: adventitious presence

Several principles are implemented in all types of activities and operations by each company:

- A quality assurance system is implemented, whereby every GM plant material is recorded and can therefore be traced.
- SOPs[49] are written for all aspects of the handling of GM beet plants and GM beet seed and the staff is trained and briefed on their use and application.
- Conventional and GM seed are handled separately, and specific labels or the unique identifier will be used for all GM material.
- The above mentioned breeding companies have agreed in sharing information on the locations and traits of their respective GM seed production worldwide.

5.2 Testing procedures

- Testing for adventitious presence of GM in conventional seed lots and for unintended events in GM seed lots.
- Exchange information on detection methods of such traits which are shortly before production.

More detailed information can be found in the Annexes.

Annex 1
Data sheet for "R&D activities for GM and Non-GM (all stages of seed development up to the basic seed production of regulated and deregulated GM beet)".

Preventive measures

- All activities involving GM beet plants and GM beet seed are subject of national and international regulations which are adhered to by the breeding companies.
- By sharing information between breeding companies about the locations and traits of their respective GM seed production, companies will have the opportunity to redefine their location of seed production in case it is located close to a conventional seed or another GM event production area.
- Minimum of four years of rotation between GM beet seed-crop and conventional beet root-crop.
- Isolation distance of at least 1.5 miles between GM and conventional or other GM event seed production.
- Bolting plants of *Beta* species are removed within a radius of at least 1000 m around GM multiplications before flowering.
- SOPs are written for all aspects of the handling of GM beet plants and GM beet seed and the staff is trained and briefed on their use and application.
- Transport of GM seed only in closed containers or bags.
- Storage of GM seed in dedicated areas separated from conventional seed.
- Careful cleaning of all machinery is carried out before and after each step in the production process of a GM seed lot or separate production lines (different GM, Non-GM) are used in the production process.
- Monitoring for volunteer beets is done at fields or locations used for GM seed production
- Shallow post harvest tillage

[49] SOP: standard operating procedure

Testing procedures

- Seed lots are tested for the adventitious presence of GM and GM seed lots for unintended GMO before shipment to third parties, for example:
    - Testing of conventional seed lots used for variety trials.
    - Testing of GM seed lots used for variety trials.
    - Testing of conventional seed lots used in field trials by research institutes and/or industry.
    - Testing of GM seed lots used in field trials by research institutes and/or industry.

- Basic seed lots used for commercial production are tested by either PCR or immunological tests and/or herbicide application in case of herbicide tolerance traits.
- Seeds are sampled after harvesting or before pelleting according to internationally accepted sampling techniques.

Annex 2
Data sheet for "Production of conventional beet seed for commercialization"

Preventive measures

- The above mentioned breeding companies have agreed in sharing information on the locations and traits of their respective GM seed multiplications worldwide.
- In addition, as part of the information sharing, breeding companies will exchange information on detection methods of such traits which are shortly before production.
- Isolation distance of at least 1.5 miles between GM and conventional seed production.
- Bolting plants of *Beta* species are removed before flowering within a radius of 1000 m around GM multiplications.
- Minimum of four years crop rotation in seed production.
- Separation of conventional and GM seed during processing
- The order of lots processed and pelleted is thoroughly recorded.
- Careful cleaning of all machinery is carried out before and after each step in the production process or use of separate production lines (GM, Non-GM) in the production process

Testing procedures

- Conventional seed lots are tested for adventitious presence of GM seed by either PCR or immunological tests and/or herbicide application.
- Seeds are sampled after harvesting or before pelleting according to internationally accepted sampling techniques.

Annex 3
Data sheet for "Production of GM seed for commercialization"

Preventive measures

- All activities involving GM beet plants and GM beet seed are subject of national and international regulations which are adhered to by the breeding companies.
- SOPs are written for all aspects of the handling of GM beet plants and GM beet seed and the staff is trained and briefed on their use and application.
- The above mentioned breeding companies have agreed in sharing information on the locations and traits of their respective GM seed multiplications worldwide.
- In addition, as part of the information sharing, breeding companies will exchange information on the appropriate detection method for GM traits.
- A quality assurance system is implemented, whereby every GM plant material is recorded and can therefore be traced.
- Isolation distance of at least 1.5 miles between GM and conventional seed production.
- Bolting plants of *Beta* species are removed before flowering within a radius of 1000 m around GM multiplications.
- The order of lots processed and pelleted is thoroughly recorded.
- Careful cleaning of all machinery is carried out before and after each step in the production process or use of separate production lines (GM, Non-GM) in the production process

Testing procedures

- GM seed is tested by either PCR or immunological tests and/or herbicide application in case of herbicide tolerance traits.

Seeds are sampled after harvesting or before pelleting according to internationally accepted sampling techniques.

Appendix D

Sugar Beet Production by County and State

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	California	Fresno	6,000	5,200	31.7	154,000	16.26
Sugarbeets	2008	California	Kings	1,100	1,000	36.0	36,000	16.66
Sugarbeets	2008	California	D51 Combined Counties	500	500	36.0	18,000	15.82
Sugarbeets	2008	California	D51 San Joaquin Valley	7,600	7,300	32.6	238,000	16.26
Sugarbeets	2008	California	Imperial	15,500	18,100	42.5	770,000	16.65
Sugarbeets	2008	California	D60 Southern California	15,500	15,100	42.5	770,000	16.65
Sugarbeets	**2008**	**California**	**State Total**	**28,100**	**25,400**	**39.7**	**1,008,000**	**16.56**
Sugarbeets	2008	Colorado	Boulder	500	500	22.6	11,300	16.78
Sugarbeets	2008	Colorado	Larimer	2,800	2,100	24.0	50,400	16.17
Sugarbeets	2008	Colorado	Logan	4,300	3,800	24.7	93,600	15.75
Sugarbeets	2008	Colorado	Morgan	1,800	1,800	24.8	55,900	14.86
Sugarbeets	2008	Colorado	Sedgwick	1,400	1,300	27.4	35,600	16.62
Sugarbeets	2008	Colorado	Weld	11,700	9,200	27.6	257,000	16.01
Sugarbeets	2008	Colorado	D20 Northeast	22,300	16,400	26.4	455,000	15.96
Sugarbeets	2008	Colorado	Phillips	4,200	3,400	24.6	84,600	16.86
Sugarbeets	2008	Colorado	Washington	1,500	1,300	27.2	35,300	16.00
Sugarbeets	2008	Colorado	Yuma	5,000	4,700	27.9	131,000	16.41
Sugarbeets	2008	Colorado	D80 Combined Counties	800	800	27.6	22,100	16.36
Sugarbeets	2008	Colorado	D80 East Central	11,500	10,200	26.8	273,000	16.44
Sugarbeets	**2008**	**Colorado**	**State Total**	**33,800**	**28,600**	**26.5**	**758,000**	**16.13**
Sugarbeets	2008	Idaho	Ada	1,800	1,500	36.0	54,000	15.76
Sugarbeets	2008	Idaho	Canyon	6,700	6,200	35.8	222,000	16.20
Sugarbeets	2008	Idaho	Elmore	5,800	5,300	31.6	167,500	15.84
Sugarbeets	2008	Idaho	Owyhee	2,700	2,600	35.6	92,500	16.06
Sugarbeets	2008	Idaho	Washington	1,200	1,100	34.3	37,700	16.06
Sugarbeets	2008	Idaho	D70 Combined Counties	1,000	800	32.9	26,300	16.21
Sugarbeets	2008	Idaho	D70 Southwest	18,000	17,500	34.3	600,000	16.09
Sugarbeets	2008	Idaho	Blaine	900	800	31.3	25,000	17.29
Sugarbeets	2008	Idaho	Cassia	25,400	20,100	29.9	600,000	17.79
Sugarbeets	2008	Idaho	Gooding	1,000	600	33.3	20,000	17.76
Sugarbeets	2008	Idaho	Jerome	11,000	9,700	32.6	316,000	17.80
Sugarbeets	2008	Idaho	Lincoln	3,700	3,100	29.0	90,000	16.32
Sugarbeets	2008	Idaho	Minidoka	30,100	20,100	29.4	592,000	17.93
Sugarbeets	2008	Idaho	Twin Falls	7,900	5,600	31.6	177,000	17.12
Sugarbeets	2008	Idaho	D80 South Central	50,000	88,000	30.2	2,654,000	17.78
Sugarbeets	2008	Idaho	Bingham	20,000	16,500	31.4	520,000	17.32
Sugarbeets	2008	Idaho	Power	12,000	11,000	32.3	355,000	17.18
Sugarbeets	2008	Idaho	D90 East	32,000	26,500	31.7	835,000	17.27
Sugarbeets	**2008**	**Idaho**	**State Total**	**131,000**	**116,000**	**31.2**	**3,619,000**	**17.37**
Sugarbeets	2008	Michigan	D30 Combined Counties	300	300	36.7	11,000	15.10
Sugarbeets	2008	Michigan	D30 Northeast	300	300	36.7	11,000	15.10
Sugarbeets	2008	Michigan	Glaswin	900	900	22.2	20,000	17.80
Sugarbeets	2008	Michigan	Gratiot	10,100	10,000	24.0	240,000	15.00
Sugarbeets	2008	Michigan	Isabella	700	700	24.3	17,000	17.70
Sugarbeets	2008	Michigan	Midland	3,000	3,000	26.3	79,000	15.00
Sugarbeets	2008	Michigan	Montcalm	400	400	27.5	11,000	17.50
Sugarbeets	2008	Michigan	D50 Central	15,100	15,000	24.5	367,000	15.00
Sugarbeets	2008	Michigan	Arenac	3,100	3,100	28.1	87,000	15.30
Sugarbeets	2008	Michigan	Bay	12,600	12,600	27.1	341,000	15.00
Sugarbeets	2008	Michigan	Huron	45,600	46,800	28.6	1,336,000	15.30
Sugarbeets	2008	Michigan	Saginaw	15,300	15,300	28.2	432,000	15.00
Sugarbeets	2008	Michigan	Sanilac	21,200	21,100	32.2	680,000	15.10
Sugarbeets	2008	Michigan	Tuscola	18,600	18,100	30.1	544,000	15.30
Sugarbeets	2008	Michigan	D80 East Central	116,500	116,000	29.2	3,390,000	15.20
Sugarbeets	2008	Michigan	Clinton	700	800	28.0	14,000	17.50
Sugarbeets	2008	Michigan	Ionia	600	300	30.0	9,000	17.50
Sugarbeets	2008	Michigan	Shiawassee	1,300	1,300	30.0	39,000	17.20
Sugarbeets	2008	Michigan	D20 South Central	2,500	2,100	29.5	62,000	17.30
Sugarbeets	2008	Michigan	Genesee	300	300	26.7	8,000	15.10
Sugarbeets	2008	Michigan	Lapeer	1,100	1,100	30.0	33,000	17.30
Sugarbeets	2008	Michigan	St Clair	1,200	1,200	26.7	32,000	15.70
Sugarbeets	2008	Michigan	D90 Southeast	2,800	2,600	28.1	73,000	15.00
Sugarbeets	**2008**	**Michigan**	**State Total**	**137,000**	**136,000**	**28.7**	**3,903,000**	**16.10**
Sugarbeets	2008	Minnesota	Becker	8,600	7,300	21.4	156,000	17.10
Sugarbeets	2008	Minnesota	Clay	46,000	36,000	23.0	575,100	16.80
Sugarbeets	2008	Minnesota	Kittson	33,000	32,700	25.0	817,000	16.10
Sugarbeets	2008	Minnesota	Mahnomen	2,700	1,700	22.2	37,800	17.00
Sugarbeets	2008	Minnesota	Marshall	41,500	41,200	24.8	1,020,300	17.60
Sugarbeets	2008	Minnesota	Norman	39,100	35,000	24.2	846,500	17.10
Sugarbeets	2008	Minnesota	Polk	69,000	88,200	26.5	2,335,000	17.50
Sugarbeets	2008	Minnesota	Red Lake	1,200	1,100	25.2	23,400	17.30
Sugarbeets	2008	Minnesota	D10 Combined Counties	400	300	25.3	5,600	17.30
Sugarbeets	2008	Minnesota	D10 Northwest	261,600	245,600	24.9	6,124,600	17.50
Sugarbeets	2008	Minnesota	Chippewa	30,000	29,800	23.0	654,200	17.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	California	Fresno	6,000	5,200	31.7	164,000	16.26
Sugarbeets	2008	California	Kings	1,100	1,000	36.0	36,000	16.66
Sugarbeets	2008	California	D51 Combined Counties	500	500	36.0	18,000	15.62
Sugarbeets	2008	California	D51 San Joaquin Valley	7,600	7,300	32.6	238,000	16.26
Sugarbeets	2008	California	Imperial	18,500	18,100	42.5	770,000	16.85
Sugarbeets	2008	California	D60 Southern California	18,500	15,100	42.5	770,000	16.85
Sugarbeets	**2008**	**California**	**State Total**	**26,100**	**25,400**	**39.7**	**1,008,000**	**16.56**
Sugarbeets	2008	Colorado	Boulder	500	500	22.6	11,300	16.78
Sugarbeets	2008	Colorado	Larimer	2,800	2,100	24.0	50,400	16.17
Sugarbeets	2008	Colorado	Logan	4,300	3,800	24.7	93,900	15.75
Sugarbeets	2008	Colorado	Morgan	1,800	1,600	24.6	39,900	14.88
Sugarbeets	2008	Colorado	Sedgwick	1,400	1,300	27.4	35,600	16.62
Sugarbeets	2008	Colorado	Weld	11,700	9,200	27.9	257,000	16.01
Sugarbeets	2008	Colorado	D20 Northeast	22,300	18,400	25.4	465,000	15.95
Sugarbeets	2008	Colorado	Phillips	4,200	3,400	24.9	84,600	16.68
Sugarbeets	2008	Colorado	Washington	1,500	1,300	27.2	35,300	16.00
Sugarbeets	2008	Colorado	Yuma	5,000	4,700	27.9	131,000	16.41
Sugarbeets	2008	Colorado	D60 Combined Counties	800	800	27.8	22,100	16.36
Sugarbeets	2008	Colorado	D60 East Central	11,500	10,200	26.8	273,000	16.44
Sugarbeets	**2008**	**Colorado**	**State Total**	**33,800**	**28,600**	**26.5**	**758,000**	**16.13**
Sugarbeets	2008	Idaho	Ada	1,800	1,500	36.0	54,000	15.78
Sugarbeets	2008	Idaho	Canyon	6,700	6,200	35.8	222,000	16.20
Sugarbeets	2008	Idaho	Elmore	5,800	5,300	31.6	167,500	15.84
Sugarbeets	2008	Idaho	Owyhee	2,700	2,600	35.6	92,500	16.06
Sugarbeets	2008	Idaho	Washington	1,200	1,100	34.3	37,700	16.96
Sugarbeets	2008	Idaho	D70 Combined Counties	1,000	800	32.9	26,300	16.21
Sugarbeets	2008	Idaho	D70 Southwest	19,000	17,500	34.3	600,000	16.09
Sugarbeets	2008	Idaho	Blaine	900	800	31.3	25,000	17.29
Sugarbeets	2008	Idaho	Cassia	25,400	20,100	29.9	600,000	17.79
Sugarbeets	2008	Idaho	Gooding	1,000	600	33.3	20,000	17.76
Sugarbeets	2008	Idaho	Jerome	11,000	9,700	32.8	316,000	17.69
Sugarbeets	2008	Idaho	Lincoln	3,700	3,100	29.0	93,000	16.32
Sugarbeets	2008	Idaho	Minidoka	30,100	29,100	29.4	856,000	17.93
Sugarbeets	2008	Idaho	Twin Falls	7,900	5,600	31.6	177,000	17.12
Sugarbeets	2008	Idaho	D80 South Central	50,000	69,000	30.2	2,054,000	17.79
Sugarbeets	2008	Idaho	Bingham	20,000	18,500	31.4	580,000	17.32
Sugarbeets	2008	Idaho	Power	12,000	11,000	32.3	355,000	17.18
Sugarbeets	2008	Idaho	D90 East	32,000	29,500	31.7	935,000	17.27
Sugarbeets	**2008**	**Idaho**	**State Total**	**131,000**	**116,000**	**31.2**	**3,619,000**	**17.37**
Sugarbeets	2008	Michigan	D30 Combined Counties	300	300	36.7	11,000	16.10
Sugarbeets	2008	Michigan	D30 Northeast	300	300	36.7	11,000	16.10
Sugarbeets	2008	Michigan	Gladwin	900	900	22.2	20,000	17.80
Sugarbeets	2008	Michigan	Gratiot	10,100	10,000	24.0	240,000	16.00
Sugarbeets	2008	Michigan	Isabella	700	700	24.3	17,000	17.70
Sugarbeets	2008	Michigan	Midland	3,000	3,000	26.3	79,000	16.00
Sugarbeets	2008	Michigan	Montcalm	400	400	27.5	11,000	17.50
Sugarbeets	2008	Michigan	D50 Central	15,100	15,000	24.5	367,000	16.00
Sugarbeets	2008	Michigan	Arenac	3,100	3,100	28.1	87,000	16.30
Sugarbeets	2008	Michigan	Bay	12,600	12,600	27.1	341,000	16.00
Sugarbeets	2008	Michigan	Huron	48,800	48,800	28.6	1,395,000	16.30
Sugarbeets	2008	Michigan	Saginaw	15,300	15,300	25.2	432,000	16.00
Sugarbeets	2008	Michigan	Sanilac	21,200	21,100	32.2	680,000	16.10
Sugarbeets	2008	Michigan	Tuscola	18,500	18,100	30.1	544,000	16.30
Sugarbeets	2008	Michigan	D60 East Central	116,500	116,000	29.2	3,390,000	16.20
Sugarbeets	2008	Michigan	Clinton	700	500	28.0	14,000	17.50
Sugarbeets	2008	Michigan	Ionia	500	300	30.0	9,000	17.50
Sugarbeets	2008	Michigan	Shiawassee	1,300	1,300	30.0	39,000	17.20
Sugarbeets	2008	Michigan	D80 South Central	2,500	2,100	29.5	62,000	17.30
Sugarbeets	2008	Michigan	Genesee	300	300	28.7	8,000	16.10
Sugarbeets	2008	Michigan	Lapeer	1,100	1,100	30.0	33,000	17.30
Sugarbeets	2008	Michigan	St Clair	1,200	1,200	28.7	32,000	16.70
Sugarbeets	2008	Michigan	D90 Southeast	2,600	2,600	28.1	73,000	16.00
Sugarbeets	**2008**	**Michigan**	**State Total**	**137,000**	**136,000**	**28.7**	**3,903,000**	**16.10**
Sugarbeets	2008	Minnesota	Becker	8,800	7,300	21.4	156,000	17.10
Sugarbeets	2008	Minnesota	Clay	48,000	38,000	23.0	875,100	16.80
Sugarbeets	2008	Minnesota	Kittson	33,000	32,700	25.0	817,000	15.10
Sugarbeets	2008	Minnesota	Mahnomen	2,700	1,700	22.2	37,800	17.00
Sugarbeets	2008	Minnesota	Marshall	41,600	41,200	24.8	1,020,300	17.90
Sugarbeets	2008	Minnesota	Norman	39,100	35,000	24.2	846,500	17.10
Sugarbeets	2008	Minnesota	Polk	59,000	68,200	26.6	2,325,000	17.50
Sugarbeets	2008	Minnesota	Red Lake	1,200	1,100	25.8	28,400	17.30
Sugarbeets	2008	Minnesota	D10 Combined Counties	400	300	25.3	5,600	17.30
Sugarbeets	2008	Minnesota	D10 Northwest	261,600	245,500	24.9	6,124,900	17.50
Sugarbeets	2008	Minnesota	Chippewa	30,000	29,800	23.0	654,200	17.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	California	Fresno	6,000	5,800	31.7	184,000	16.26
Sugarbeets	2008	California	Kings	1,100	1,000	36.0	36,000	16.06
Sugarbeets	2008	California	D51 Combined Counties	500	500	36.0	18,000	15.82
Sugarbeets	2008	California	D51 San Joaquin Valley	7,600	7,300	32.6	238,000	16.26
Sugarbeets	2008	California	Imperial	18,600	18,100	42.6	770,000	16.66
Sugarbeets	2008	California	D60 Southern California	18,600	18,100	42.6	770,000	16.66
Sugarbeets	**2008**	**California**	**State Total**	**26,100**	**25,400**	**39.7**	**1,008,000**	**16.36**
Sugarbeets	2008	Colorado	Boulder	500	500	22.8	11,300	16.78
Sugarbeets	2008	Colorado	Larimer	2,800	2,100	24.0	50,400	16.17
Sugarbeets	2008	Colorado	Logan	4,300	3,200	24.7	93,800	15.75
Sugarbeets	2008	Colorado	Morgan	1,800	1,500	24.8	36,900	14.80
Sugarbeets	2008	Colorado	Sedgwick	1,400	1,300	27.4	35,800	16.62
Sugarbeets	2008	Colorado	Weld	11,700	9,200	27.9	257,000	16.01
Sugarbeets	2008	Colorado	D20 Northeast	22,300	18,400	26.4	485,000	15.95
Sugarbeets	2008	Colorado	Phillips	4,200	3,400	24.9	84,600	16.50
Sugarbeets	2008	Colorado	Washington	1,500	1,300	27.2	35,300	16.00
Sugarbeets	2008	Colorado	Yuma	5,000	4,700	27.9	131,000	16.41
Sugarbeets	2008	Colorado	D80 Combined Counties	900	800	27.6	22,100	16.38
Sugarbeets	2008	Colorado	D80 East Central	11,500	10,200	26.8	273,000	16.44
Sugarbeets	**2008**	**Colorado**	**State Total**	**33,800**	**28,600**	**26.5**	**758,000**	**16.13**
Sugarbeets	2008	Idaho	Ada	1,800	1,500	36.0	54,000	15.76
Sugarbeets	2008	Idaho	Canyon	6,700	6,200	35.8	222,000	16.20
Sugarbeets	2008	Idaho	Elmore	5,800	5,300	31.6	167,500	15.84
Sugarbeets	2008	Idaho	Owyhee	2,700	2,600	35.6	92,500	16.06
Sugarbeets	2008	Idaho	Washington	1,200	1,100	34.3	37,700	16.96
Sugarbeets	2008	Idaho	D70 Combined Counties	1,000	800	32.9	26,300	16.21
Sugarbeets	2008	Idaho	D70 Southwest	19,000	17,500	34.3	600,000	16.09
Sugarbeets	2008	Idaho	Blaine	900	800	31.3	25,000	17.29
Sugarbeets	2008	Idaho	Cassia	25,400	20,100	29.9	600,000	17.79
Sugarbeets	2008	Idaho	Gooding	1,000	600	33.3	20,000	17.76
Sugarbeets	2008	Idaho	Jerome	11,000	9,700	32.6	316,000	17.69
Sugarbeets	2008	Idaho	Lincoln	3,700	3,100	29.0	90,000	16.32
Sugarbeets	2008	Idaho	Minidoka	30,100	29,100	29.4	856,000	17.93
Sugarbeets	2008	Idaho	Twin Falls	7,900	5,600	31.6	177,000	17.12
Sugarbeets	2008	Idaho	D80 South Central	50,000	69,000	30.2	2,054,000	17.76
Sugarbeets	2008	Idaho	Bingham	20,000	18,500	31.4	580,000	17.32
Sugarbeets	2008	Idaho	Power	12,000	11,000	32.3	355,000	17.18
Sugarbeets	2008	Idaho	D80 East	32,000	29,500	31.7	935,000	17.07
Sugarbeets	**2008**	**Idaho**	**State Total**	**131,000**	**116,000**	**31.2**	**3,619,000**	**17.37**
Sugarbeets	2008	Michigan	D30 Combined Counties	300	300	36.7	11,000	15.10
Sugarbeets	2008	Michigan	D30 Northeast	300	300	36.7	11,000	15.10
Sugarbeets	2008	Michigan	Gladwin	900	900	22.2	20,000	17.80
Sugarbeets	2008	Michigan	Gratiot	10,100	10,000	24.0	240,000	16.00
Sugarbeets	2008	Michigan	Isabella	700	700	24.3	17,000	17.70
Sugarbeets	2008	Michigan	Midland	3,000	3,000	26.3	79,000	16.00
Sugarbeets	2008	Michigan	Montcalm	400	400	27.5	11,000	17.50
Sugarbeets	2008	Michigan	D50 Central	15,100	15,000	24.5	367,000	16.00
Sugarbeets	2008	Michigan	Arenac	3,100	3,100	28.1	87,000	16.30
Sugarbeets	2008	Michigan	Bay	12,600	12,600	27.1	341,000	16.00
Sugarbeets	2008	Michigan	Huron	45,600	45,600	28.5	1,305,000	16.30
Sugarbeets	2008	Michigan	Saginaw	15,300	15,300	28.3	433,000	16.00
Sugarbeets	2008	Michigan	Sanilac	21,200	21,100	32.2	680,000	16.10
Sugarbeets	2008	Michigan	Tuscola	18,600	18,100	30.1	544,000	16.30
Sugarbeets	2008	Michigan	D60 East Central	116,500	116,000	29.2	3,390,000	16.20
Sugarbeets	2008	Michigan	Clinton	700	800	28.0	14,000	17.50
Sugarbeets	2008	Michigan	Ionia	500	300	30.0	9,000	17.50
Sugarbeets	2008	Michigan	Shiawassee	1,300	1,300	30.0	39,000	17.20
Sugarbeets	2008	Michigan	D80 South Central	2,500	2,100	29.5	62,000	17.30
Sugarbeets	2008	Michigan	Genesee	300	300	26.7	8,000	16.10
Sugarbeets	2008	Michigan	Lapeer	1,100	1,100	30.0	33,000	17.30
Sugarbeets	2008	Michigan	St. Clair	1,200	1,200	26.7	32,000	16.70
Sugarbeets	2008	Michigan	D90 Southeast	2,600	2,600	28.1	73,000	16.00
Sugarbeets	**2008**	**Michigan**	**State Total**	**137,000**	**136,000**	**28.7**	**3,903,000**	**16.10**
Sugarbeets	2008	Minnesota	Becker	5,800	7,300	21.4	156,000	17.10
Sugarbeets	2008	Minnesota	Clay	46,000	39,000	23.0	675,100	16.80
Sugarbeets	2008	Minnesota	Kittson	33,000	32,700	25.0	817,000	16.10
Sugarbeets	2008	Minnesota	Mahnomen	2,700	1,700	22.2	37,800	17.00
Sugarbeets	2008	Minnesota	Marshall	41,500	41,200	24.8	1,022,300	17.90
Sugarbeets	2008	Minnesota	Norman	39,100	35,000	24.2	846,800	17.10
Sugarbeets	2008	Minnesota	Polk	89,000	88,200	26.5	2,335,000	17.50
Sugarbeets	2008	Minnesota	Red Lake	1,200	1,100	25.8	28,400	17.30
Sugarbeets	2008	Minnesota	D10 Combined Counties	400	300	25.3	6,600	17.30
Sugarbeets	2008	Minnesota	D10 Northwest	261,500	245,500	24.9	6,124,900	17.50
Sugarbeets	2008	Minnesota	Chippewa	30,000	29,800	23.0	654,200	17.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	California	Fresno	6,000	5,800	31.7	184,000	16.26
Sugarbeets	2008	California	Kings	1,100	1,000	36.0	36,000	16.86
Sugarbeets	2008	California	D51 Combined Counties	500	500	36.0	18,000	16.80
Sugarbeets	2008	California	D51 San Joaquin Valley	7,600	7,300	32.6	238,000	16.26
Sugarbeets	2008	California	Imperial	18,500	18,100	42.5	770,000	16.85
Sugarbeets	2008	California	D60 Southern California	18,500	18,100	42.5	770,000	16.85
Sugarbeets	**2008**	**California**	**State Total**	**26,100**	**25,400**	**39.7**	**1,008,000**	**16.56**
Sugarbeets	2008	Colorado	Boulder	500	500	22.6	11,300	16.78
Sugarbeets	2008	Colorado	Larimer	2,800	2,100	24.0	50,400	16.17
Sugarbeets	2008	Colorado	Logan	4,300	3,800	24.7	93,850	15.75
Sugarbeets	2008	Colorado	Morgan	1,600	1,500	24.8	36,900	14.86
Sugarbeets	2008	Colorado	Sedgwick	1,400	1,300	27.4	35,600	16.82
Sugarbeets	2008	Colorado	Weld	11,700	9,200	27.9	257,000	16.01
Sugarbeets	2008	Colorado	D20 Northeast	22,300	18,400	25.4	465,000	15.95
Sugarbeets	2008	Colorado	Phillips	4,200	3,400	24.9	84,650	16.89
Sugarbeets	2008	Colorado	Washington	1,500	1,300	27.2	35,350	16.00
Sugarbeets	2008	Colorado	Yuma	5,000	4,700	27.9	131,000	16.41
Sugarbeets	2008	Colorado	D80 Combined Counties	800	800	27.6	22,100	16.36
Sugarbeets	2008	Colorado	D80 East Central	11,500	10,200	26.8	273,000	16.44
Sugarbeets	**2008**	**Colorado**	**State Total**	**33,800**	**28,600**	**26.5**	**758,000**	**16.13**
Sugarbeets	2008	Idaho	Ada	1,600	1,500	36.0	54,000	15.78
Sugarbeets	2008	Idaho	Canyon	6,700	6,200	35.8	222,000	16.20
Sugarbeets	2008	Idaho	Elmore	5,800	5,300	31.6	167,500	15.94
Sugarbeets	2008	Idaho	Owyhee	2,700	2,600	35.6	92,500	16.06
Sugarbeets	2008	Idaho	Washington	1,200	1,100	34.3	37,750	16.96
Sugarbeets	2008	Idaho	D70 Combined Counties	1,000	800	32.9	26,300	16.21
Sugarbeets	2008	Idaho	D70 Southwest	19,000	17,500	34.3	600,000	16.09
Sugarbeets	2008	Idaho	Blaine	900	800	31.3	25,050	17.29
Sugarbeets	2008	Idaho	Cassia	25,400	20,100	29.9	600,000	17.79
Sugarbeets	2008	Idaho	Gooding	1,000	600	33.3	20,000	17.76
Sugarbeets	2008	Idaho	Jerome	11,000	9,700	32.8	316,000	17.86
Sugarbeets	2008	Idaho	Lincoln	3,700	3,100	29.0	90,000	16.32
Sugarbeets	2008	Idaho	Minidoka	30,100	29,100	29.4	855,000	17.93
Sugarbeets	2008	Idaho	Twin Falls	7,900	5,600	31.6	177,000	17.12
Sugarbeets	2008	Idaho	D80 South Central	69,000	69,000	30.2	2,084,000	17.79
Sugarbeets	2008	Idaho	Bingham	20,000	18,500	31.4	580,000	17.32
Sugarbeets	2008	Idaho	Power	12,000	11,000	32.3	355,000	17.18
Sugarbeets	2008	Idaho	D90 East	32,000	29,000	31.7	935,000	17.27
Sugarbeets	**2008**	**Idaho**	**State Total**	**131,000**	**116,000**	**31.2**	**3,619,000**	**17.37**
Sugarbeets	2008	Michigan	D30 Combined Counties	300	300	36.7	11,000	16.10
Sugarbeets	2008	Michigan	D30 Northeast	300	300	36.7	11,050	15.10
Sugarbeets	2008	Michigan	Gladwin	900	900	22.2	20,000	17.80
Sugarbeets	2008	Michigan	Gratiot	10,100	10,000	24.0	240,000	15.00
Sugarbeets	2008	Michigan	Isabella	700	700	24.3	17,000	17.70
Sugarbeets	2008	Michigan	Midland	3,000	3,000	26.3	79,000	15.00
Sugarbeets	2008	Michigan	Montcalm	400	400	27.5	11,000	17.50
Sugarbeets	2008	Michigan	D50 Central	15,100	15,000	24.5	367,000	15.00
Sugarbeets	2008	Michigan	Arenac	3,100	3,100	26.1	57,000	15.30
Sugarbeets	2008	Michigan	Bay	12,600	12,600	27.1	341,000	15.00
Sugarbeets	2008	Michigan	Huron	45,800	45,800	26.5	1,304,000	15.90
Sugarbeets	2008	Michigan	Saginaw	15,300	15,300	25.2	432,000	16.00
Sugarbeets	2008	Michigan	Sanilac	21,200	21,100	32.3	660,000	15.10
Sugarbeets	2008	Michigan	Tuscola	18,500	18,100	30.1	544,000	15.30
Sugarbeets	2008	Michigan	D60 East Central	116,500	116,000	29.2	3,390,000	15.20
Sugarbeets	2008	Michigan	Clinton	700	500	28.0	14,000	17.50
Sugarbeets	2008	Michigan	Ionia	500	300	30.0	9,000	17.50
Sugarbeets	2008	Michigan	Shiawassee	1,300	1,300	30.0	39,000	17.20
Sugarbeets	2008	Michigan	D80 South Central	2,500	2,100	29.5	62,000	17.30
Sugarbeets	2008	Michigan	Genesee	300	300	26.7	8,000	18.10
Sugarbeets	2008	Michigan	Lapeer	1,100	1,100	30.0	33,000	17.30
Sugarbeets	2008	Michigan	St Clair	1,200	1,200	26.7	32,000	15.70
Sugarbeets	2008	Michigan	D90 Southeast	2,600	2,600	28.1	73,000	15.00
Sugarbeets	**2008**	**Michigan**	**State Total**	**137,000**	**136,000**	**28.7**	**3,903,000**	**16.10**
Sugarbeets	2008	Minnesota	Becker	8,600	7,900	21.4	166,000	17.10
Sugarbeets	2008	Minnesota	Clay	46,000	38,000	23.0	575,100	16.80
Sugarbeets	2008	Minnesota	Kittson	33,000	32,700	25.0	517,000	16.10
Sugarbeets	2008	Minnesota	Mahnomen	2,700	1,700	22.2	37,800	17.00
Sugarbeets	2008	Minnesota	Marshall	41,500	41,200	24.8	1,020,300	17.90
Sugarbeets	2008	Minnesota	Norman	39,100	36,000	24.2	646,500	17.10
Sugarbeets	2008	Minnesota	Polk	59,000	88,200	26.5	2,335,000	17.50
Sugarbeets	2008	Minnesota	Red Lake	1,200	1,100	25.8	28,400	17.30
Sugarbeets	2008	Minnesota	D10 Combined Counties	400	300	25.3	8,500	17.30
Sugarbeets	2008	Minnesota	D10 Northwest	251,500	245,200	24.9	6,124,900	17.50
Sugarbeets	2008	Minnesota	Chippewa	30,000	29,800	23.0	664,200	17.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Minnesota	Grant	9,400	9,300	22.1	205,500	16.70
Sugarbeets	2008	Minnesota	Otter Tail	3,400	3,100	23.7	73,500	16.40
Sugarbeets	2008	Minnesota	Pope	1,800	1,500	21.9	32,900	17.50
Sugarbeets	2008	Minnesota	Stevens	4,400	4,300	25.0	107,300	17.20
Sugarbeets	2008	Minnesota	Swift	6,400	6,200	25.9	160,100	17.40
Sugarbeets	2008	Minnesota	Traverse	8,600	8,200	22.3	182,500	17.00
Sugarbeets	2008	Minnesota	Wilkin	45,100	25,700	25.4	653,000	16.30
Sugarbeets	2008	Minnesota	Yellow Medicine	3,200	3,100	21.6	66,600	17.00
Sugarbeets	2008	Minnesota	D40 Combined Counties	900	800	20.9	16,700	17.10
Sugarbeets	2008	Minnesota	D40 West Central	116,000	92,000	23.7	2,182,300	16.80
Sugarbeets	2008	Minnesota	Kandiyohi	14,500	14,400	26.2	376,500	17.20
Sugarbeets	2008	Minnesota	McLeod	1,500	1,400	24.4	34,100	16.70
Sugarbeets	2008	Minnesota	Renville	32,700	32,500	25.2	820,300	17.00
Sugarbeets	2008	Minnesota	Sibley	3,200	3,200	24.8	79,700	16.60
Sugarbeets	2008	Minnesota	Stearns	2,100	2,000	22.4	44,700	17.30
Sugarbeets	2008	Minnesota	D50 Combined Counties	3,500	3,400	26.6	90,500	17.00
Sugarbeets	2008	Minnesota	D50 Central	57,500	56,900	25.4	1,445,900	17.00
Sugarbeets	2008	Minnesota	Lyon	400	400	15.3	6,100	17.80
Sugarbeets	2008	Minnesota	Redwood	3,600	3,400	22.8	76,800	16.70
Sugarbeets	2008	Minnesota	D70 Combined Counties	300	200	18.5	3,700	17.20
Sugarbeets	2008	Minnesota	D70 Southwest	4,200	4,000	21.7	86,800	16.80
Sugarbeets	2008	Minnesota	D98 Combined Districts	800	800	25.5	15,300	16.30
Sugarbeets	**2008**	**Minnesota**	**State Total**	**440,000**	**399,000**	**24.7**	**9,855,000**	**17.25**
Sugarbeets	2008	Montana	D30 Combined Counties	6,900	6,900	24.9	171,900	16.32
Sugarbeets	2008	Montana	D30 Northeast	6,900	6,900	24.9	171,900	16.32
Sugarbeets	2008	Montana	Big Horn	9,100	8,200	26.8	253,000	16.81
Sugarbeets	2008	Montana	Carbon	3,500	3,500	24.0	83,900	16.84
Sugarbeets	2008	Montana	Yellowstone	6,700	6,000	25.9	155,200	16.88
Sugarbeets	2008	Montana	D80 Combined Counties	3,600	3,500	25.8	100,700	17.18
Sugarbeets	2008	Montana	D80 South Central	22,600	21,200	27.2	592,500	16.96
Sugarbeets	2008	Montana	Rosebud	2,000	2,000	29.2	58,300	17.36
Sugarbeets	2008	Montana	D90 Southeast	2,000	2,000	29.2	58,300	17.36
Sugarbeets	**2008**	**Montana**	**State Total**	**31,700**	**30,700**	**26.8**	**823,000**	**17.27**
Sugarbeets	2008	Nebraska	Banner	700	400	20.3	6,300	17.17
Sugarbeets	2008	Nebraska	Box Butte	18,800	17,300	22.5	358,600	17.19
Sugarbeets	2008	Nebraska	Cheyenne	1,900	1,100	24.8	27,300	17.23
Sugarbeets	2008	Nebraska	Kimball	2,800	2,600	21.3	55,400	17.36
Sugarbeets	2008	Nebraska	Morrill	5,800	4,100	22.7	93,100	16.34
Sugarbeets	2008	Nebraska	Scotts Bluff	7,800	5,700	23.1	131,900	16.31
Sugarbeets	2008	Nebraska	Sheridan	2,600	2,400	22.1	53,100	16.85
Sugarbeets	2008	Nebraska	D10 Combined Counties	700	700	21.6	15,100	17.05
Sugarbeets	2008	Nebraska	D10 Northwest	41,100	34,300	22.5	772,600	16.94
Sugarbeets	2008	Nebraska	Chase	700	600	17.5	10,500	16.04
Sugarbeets	2008	Nebraska	Keith	2,600	1,800	25.0	45,000	17.32
Sugarbeets	2008	Nebraska	Perkins	800	800	24.5	14,700	17.03
Sugarbeets	2008	Nebraska	D70 Southwest	4,100	3,000	23.4	70,200	17.01
Sugarbeets	**2008**	**Nebraska**	**State Total**	**45,200**	**37,300**	**22.6**	**843,000**	**16.94**
Sugarbeets	2008	North Dakota	Williams	2,100	1,900	22.6	43,000	17.50
Sugarbeets	2008	North Dakota	D10 Northwest	2,100	1,900	22.6	43,000	17.50
Sugarbeets	2008	North Dakota	Grand Forks	27,200	27,000	26.7	720,900	17.65
Sugarbeets	2008	North Dakota	Pembina	59,000	58,300	25.6	1,492,000	17.78
Sugarbeets	2008	North Dakota	Walsh	40,800	40,400	26.1	1,052,000	16.07
Sugarbeets	2008	North Dakota	D30 Northeast	127,000	125,700	26.0	3,268,000	17.85
Sugarbeets	2008	North Dakota	McKenzie	6,200	5,800	24.8	144,000	16.18
Sugarbeets	2008	North Dakota	D40 West Central	6,200	5,800	24.8	144,000	16.18
Sugarbeets	2008	North Dakota	Cass	17,000	16,500	25.3	418,000	17.06
Sugarbeets	2008	North Dakota	Steele	400	400	30.0	12,000	16.72
Sugarbeets	2008	North Dakota	Traill	25,200	24,900	26.1	651,000	17.46
Sugarbeets	2008	North Dakota	D60 East Central	43,500	41,800	25.9	1,081,000	17.32
Sugarbeets	2008	North Dakota	Richland	26,800	21,400	25.9	554,000	16.37
Sugarbeets	2008	North Dakota	D90 Combined Counties	400	400	30.0	12,000	16.40
Sugarbeets	2008	North Dakota	D90 Southeast	29,200	21,800	26.0	566,000	16.37
Sugarbeets	**2008**	**North Dakota**	**State Total**	**208,000**	**197,000**	**25.9**	**5,102,000**	**17.58**
Sugarbeets	2008	Oregon	Union	1,500	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	D30 Northeast	1,500	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	Malheur	5,200	4,500	34.7	156,000	16.00
Sugarbeets	2008	Oregon	D60 Southeast	5,200	4,500	34.7	156,000	16.00
Sugarbeets	**2008**	**Oregon**	**State Total**	**6,700**	**5,900**	**33.1**	**195,000**	**16.34**
Sugarbeets	2008	Washington	Benton	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	D20 Central	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	State Total	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Wyoming	Big Horn	8,300	8,100	23.4	189,300	17.46
Sugarbeets	2008	Wyoming	Fremont	1,500	1,500	20.1	30,200	15.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Minnesota	Grant	9,400	9,300	22.1	205,500	16.70
Sugarbeets	2008	Minnesota	Otter Tail	3,400	3,100	23.7	73,500	16.40
Sugarbeets	2008	Minnesota	Pope	1,600	1,600	21.9	32,900	17.50
Sugarbeets	2008	Minnesota	Stevens	4,400	4,300	25.0	107,300	17.20
Sugarbeets	2008	Minnesota	Swift	6,400	6,200	25.2	160,100	17.40
Sugarbeets	2008	Minnesota	Traverse	6,600	6,200	22.3	152,500	17.00
Sugarbeets	2008	Minnesota	Wilkin	45,100	25,700	26.4	653,000	16.30
Sugarbeets	2008	Minnesota	Yellow Medicine	3,200	3,100	21.5	66,600	17.00
Sugarbeets	2008	Minnesota	D40 Combined Counties	900	800	20.9	16,700	17.10
Sugarbeets	2008	Minnesota	D40 West Central	115,000	92,000	23.7	2,152,300	16.80
Sugarbeets	2008	Minnesota	Kandiyohi	14,500	14,400	26.2	378,600	17.20
Sugarbeets	2008	Minnesota	McLeod	1,600	1,400	24.4	34,100	16.70
Sugarbeets	2008	Minnesota	Renville	32,700	32,600	25.2	820,300	17.00
Sugarbeets	2008	Minnesota	Sibley	3,200	3,200	24.9	79,700	16.60
Sugarbeets	2008	Minnesota	Stearns	2,100	2,000	22.4	44,700	17.30
Sugarbeets	2008	Minnesota	D50 Combined Counties	3,500	3,400	26.6	90,500	17.00
Sugarbeets	2008	Minnesota	D60 Central	57,500	56,900	25.4	1,445,900	17.00
Sugarbeets	2008	Minnesota	Lyon	400	400	15.3	6,100	17.80
Sugarbeets	2008	Minnesota	Redwood	3,600	3,400	22.6	76,800	16.70
Sugarbeets	2008	Minnesota	D70 Combined Counties	300	200	16.5	3,700	17.20
Sugarbeets	2008	Minnesota	D70 Southwest	4,200	4,000	21.7	86,850	16.80
Sugarbeets	2008	Minnesota	D88 Combined Districts	600	600	25.5	15,300	16.56
Sugarbeets	**2008**	**Minnesota**	**State Total**	**440,000**	**399,000**	**24.7**	**9,855,000**	**17.25**
Sugarbeets	2008	Montana	D30 Combined Counties	9,900	9,900	24.9	171,900	16.32
Sugarbeets	2008	Montana	D30 Northeast	9,900	9,900	24.9	171,900	16.32
Sugarbeets	2008	Montana	Big Horn	9,100	8,200	28.2	253,000	16.91
Sugarbeets	2008	Montana	Carbon	3,500	3,500	24.0	53,900	16.84
Sugarbeets	2008	Montana	Yellowstone	6,700	6,000	25.9	165,200	16.96
Sugarbeets	2008	Montana	D80 Combined Counties	3,500	3,500	25.8	100,700	17.16
Sugarbeets	2008	Montana	D80 South Central	22,800	21,800	27.2	592,600	16.96
Sugarbeets	2008	Montana	Pondera	2,000	2,000	29.2	58,300	17.36
Sugarbeets	2008	Montana	D90 Southeast	2,000	2,000	29.2	58,300	17.36
Sugarbeets	**2008**	**Montana**	**State Total**	**31,700**	**30,700**	**26.8**	**823,000**	**17.27**
Sugarbeets	2008	Nebraska	Banner	700	400	20.8	6,900	17.17
Sugarbeets	2008	Nebraska	Box Butte	18,900	17,300	22.5	388,600	17.10
Sugarbeets	2008	Nebraska	Cheyenne	1,600	1,100	24.8	27,300	17.22
Sugarbeets	2008	Nebraska	Kimball	2,600	2,600	21.3	55,400	17.36
Sugarbeets	2008	Nebraska	Morrill	5,800	4,100	22.7	93,100	16.34
Sugarbeets	2008	Nebraska	Scotts Bluff	7,800	5,700	23.1	131,900	16.31
Sugarbeets	2008	Nebraska	Sheridan	2,600	2,400	22.1	53,100	16.85
Sugarbeets	2008	Nebraska	D10 Combined Counties	700	700	21.6	15,100	17.05
Sugarbeets	2008	Nebraska	D10 Northwest	41,100	34,300	22.5	772,500	16.94
Sugarbeets	2008	Nebraska	Chase	700	600	17.5	10,500	16.04
Sugarbeets	2008	Nebraska	Keith	2,600	1,800	25.0	45,000	17.32
Sugarbeets	2008	Nebraska	Perkins	800	600	24.5	14,700	17.03
Sugarbeets	2008	Nebraska	D70 Southwest	4,100	3,000	33.4	70,200	17.01
Sugarbeets	**2008**	**Nebraska**	**State Total**	**45,200**	**37,300**	**22.6**	**843,000**	**16.94**
Sugarbeets	2008	North Dakota	Williams	2,100	1,900	22.6	43,000	17.50
Sugarbeets	2008	North Dakota	D10 Northwest	2,100	1,900	22.6	43,000	17.50
Sugarbeets	2008	North Dakota	Grand Forks	27,200	27,000	26.7	720,000	17.65
Sugarbeets	2008	North Dakota	Pembina	59,000	58,300	25.6	1,492,000	17.78
Sugarbeets	2008	North Dakota	Walsh	40,600	40,400	26.1	1,056,000	15.07
Sugarbeets	2008	North Dakota	D30 Northeast	127,000	125,700	26.0	3,268,000	17.86
Sugarbeets	2008	North Dakota	McKenzie	6,200	5,800	24.8	144,000	15.18
Sugarbeets	2008	North Dakota	D40 West Central	6,200	5,800	24.8	144,000	15.18
Sugarbeets	2008	North Dakota	Cass	17,000	16,500	25.3	418,000	17.09
Sugarbeets	2008	North Dakota	Steele	400	400	30.0	12,000	15.72
Sugarbeets	2008	North Dakota	Traill	25,200	24,900	26.1	651,000	17.48
Sugarbeets	2008	North Dakota	D60 East Central	43,600	41,800	25.9	1,081,000	17.32
Sugarbeets	2008	North Dakota	Richland	26,600	21,400	25.9	554,000	16.37
Sugarbeets	2008	North Dakota	D80 Combined Counties	400	400	30.0	12,000	15.40
Sugarbeets	2008	North Dakota	D90 Southeast	29,200	21,800	26.0	566,000	16.37
Sugarbeets	**2008**	**North Dakota**	**State Total**	**298,000**	**197,000**	**25.9**	**5,102,000**	**17.58**
Sugarbeets	2008	Oregon	Union	1,600	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	D30 Northeast	1,600	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	Malheur	5,200	4,500	34.7	156,000	16.09
Sugarbeets	2008	Oregon	D80 Southeast	5,200	4,500	34.7	156,000	16.09
Sugarbeets	**2008**	**Oregon**	**State Total**	**6,700**	**5,900**	**33.1**	**195,000**	**16.34**
Sugarbeets	2008	Washington	Benton	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	D20 Central	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	State Total	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Wyoming	Big Horn	8,300	8,100	29.4	159,300	17.46
Sugarbeets	2008	Wyoming	Fremont	1,500	1,500	30.1	59,200	15.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Minnesota	Grant	9,400	9,300	22.1	205,500	16.70
Sugarbeets	2008	Minnesota	Otter Tail	3,400	3,100	23.7	73,500	16.40
Sugarbeets	2008	Minnesota	Pope	1,600	1,500	21.9	32,900	17.60
Sugarbeets	2008	Minnesota	Stevens	4,400	4,300	25.0	107,300	17.20
Sugarbeets	2008	Minnesota	Swift	6,400	6,200	26.8	166,100	17.40
Sugarbeets	2008	Minnesota	Traverse	6,600	6,200	22.3	152,500	17.00
Sugarbeets	2008	Minnesota	Wilkin	46,100	25,700	25.4	653,000	16.30
Sugarbeets	2008	Minnesota	Yellow Medicine	3,200	3,100	21.5	66,600	17.00
Sugarbeets	2008	Minnesota	D40 Combined Counties	900	800	20.9	16,700	17.16
Sugarbeets	2008	Minnesota	D40 West Central	118,000	92,000	23.7	2,132,300	16.60
Sugarbeets	2008	Minnesota	Kandiyohi	14,500	14,400	26.2	376,600	17.20
Sugarbeets	2008	Minnesota	McLeod	1,500	1,400	24.4	34,100	16.70
Sugarbeets	2008	Minnesota	Renville	32,700	32,500	25.2	822,300	17.00
Sugarbeets	2008	Minnesota	Sibley	3,200	3,200	24.9	79,700	16.60
Sugarbeets	2008	Minnesota	Stearns	2,100	2,000	22.4	44,700	17.30
Sugarbeets	2008	Minnesota	D50 Combined Counties	3,500	3,400	26.6	90,550	17.00
Sugarbeets	2008	Minnesota	D60 Central	57,500	56,900	25.4	1,445,900	17.00
Sugarbeets	2008	Minnesota	Lyon	400	400	15.3	6,100	17.60
Sugarbeets	2008	Minnesota	Redwood	3,500	3,400	22.6	76,830	16.70
Sugarbeets	2008	Minnesota	D70 Combined Counties	300	200	15.5	3,700	17.20
Sugarbeets	2008	Minnesota	D70 Southwest	4,200	4,000	21.7	86,800	16.80
Sugarbeets	2008	Minnesota	D98 Combined Districts	800	600	25.5	15,300	16.56
Sugarbeets	**2008**	**Minnesota**	**State Total**	**449,000**	**399,000**	**24.7**	**9,855,000**	**17.25**
Sugarbeets	2008	Montana	D30 Combined Counties	6,900	6,900	24.9	171,900	16.92
Sugarbeets	2008	Montana	D30 Northeast	6,900	6,900	24.9	171,900	16.92
Sugarbeets	2008	Montana	Big Horn	9,100	8,200	28.8	253,000	16.91
Sugarbeets	2008	Montana	Carbon	3,600	3,600	24.0	53,900	16.84
Sugarbeets	2008	Montana	Yellowstone	6,700	6,000	25.9	155,200	16.96
Sugarbeets	2008	Montana	D80 Combined Counties	3,600	3,600	25.8	100,700	17.18
Sugarbeets	2008	Montana	D80 South Central	23,800	21,200	27.2	592,500	16.96
Sugarbeets	2008	Montana	Rosebud	2,000	2,000	29.2	58,300	17.36
Sugarbeets	2008	Montana	D90 Southeast	2,000	2,000	29.2	58,300	17.36
Sugarbeets	**2008**	**Montana**	**State Total**	**31,700**	**30,700**	**26.8**	**823,000**	**17.27**
Sugarbeets	2008	Nebraska	Banner	700	400	20.2	5,300	17.17
Sugarbeets	2008	Nebraska	Box Butte	18,000	17,300	22.5	388,600	17.19
Sugarbeets	2008	Nebraska	Cheyenne	1,600	1,100	24.8	27,300	17.22
Sugarbeets	2008	Nebraska	Kimball	2,800	2,600	21.3	55,400	17.36
Sugarbeets	2008	Nebraska	Morrill	5,800	4,100	23.7	93,100	16.34
Sugarbeets	2008	Nebraska	Scotts Bluff	7,800	5,700	23.1	131,900	16.31
Sugarbeets	2008	Nebraska	Sheridan	2,600	2,400	22.1	53,100	16.65
Sugarbeets	2008	Nebraska	D10 Combined Counties	700	700	21.6	15,100	17.05
Sugarbeets	2008	Nebraska	D10 Northwest	41,100	34,300	22.5	772,500	16.84
Sugarbeets	2008	Nebraska	Chase	700	600	17.5	10,500	16.04
Sugarbeets	2008	Nebraska	Keith	2,600	1,800	25.0	45,000	17.32
Sugarbeets	2008	Nebraska	Perkins	800	600	24.5	14,700	17.03
Sugarbeets	2008	Nebraska	D70 Southwest	4,100	3,000	23.4	70,200	17.01
Sugarbeets	**2008**	**Nebraska**	**State Total**	**45,200**	**37,300**	**22.6**	**843,000**	**16.94**
Sugarbeets	2008	North Dakota	Williams	2,100	1,900	22.8	43,000	17.50
Sugarbeets	2008	North Dakota	D10 Northwest	2,100	1,900	22.8	43,000	17.50
Sugarbeets	2008	North Dakota	Grand Forks	27,300	27,000	26.7	720,000	17.65
Sugarbeets	2008	North Dakota	Pembina	59,000	56,300	25.6	1,422,000	17.78
Sugarbeets	2008	North Dakota	Walsh	40,800	40,400	26.1	1,055,000	15.07
Sugarbeets	2008	North Dakota	D30 Northeast	127,000	125,700	26.0	3,268,000	17.85
Sugarbeets	2008	North Dakota	McKenzie	5,200	5,800	24.8	144,000	15.18
Sugarbeets	2008	North Dakota	D40 West Central	6,200	5,800	24.8	144,000	15.18
Sugarbeets	2008	North Dakota	Cass	17,000	16,500	25.3	418,000	17.08
Sugarbeets	2008	North Dakota	Steele	400	400	30.0	12,000	16.72
Sugarbeets	2008	North Dakota	Traill	25,200	24,600	26.1	651,000	17.48
Sugarbeets	2008	North Dakota	D60 East Central	43,600	41,800	25.9	1,081,000	17.32
Sugarbeets	2008	North Dakota	Richland	25,800	21,400	25.9	554,000	16.37
Sugarbeets	2008	North Dakota	D90 Combined Counties	400	400	30.0	12,000	16.40
Sugarbeets	2008	North Dakota	D90 Southeast	22,200	21,800	26.0	566,000	16.37
Sugarbeets	**2008**	**North Dakota**	**State Total**	**209,000**	**197,000**	**25.9**	**5,102,000**	**17.58**
Sugarbeets	2008	Oregon	Union	1,500	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	D30 Northeast	1,500	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	Malheur	5,200	4,600	34.7	156,000	16.09
Sugarbeets	2008	Oregon	D80 Southeast	5,200	4,600	34.7	156,000	16.09
Sugarbeets	**2008**	**Oregon**	**State Total**	**6,700**	**5,900**	**33.1**	**195,000**	**16.34**
Sugarbeets	2008	Washington	Benton	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	D20 Central	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	State Total	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Wyoming	Big Horn	9,300	8,100	23.4	152,300	17.46
Sugarbeets	2008	Wyoming	Fremont	1,500	1,500	20.1	30,200	15.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Minnesota	Grant	9,400	9,300	22.1	205,500	16.70
Sugarbeets	2008	Minnesota	Otter Tail	3,400	3,100	23.7	73,500	16.40
Sugarbeets	2008	Minnesota	Pope	1,600	1,500	21.9	32,900	17.60
Sugarbeets	2008	Minnesota	Stevens	4,400	4,300	25.0	107,300	17.20
Sugarbeets	2008	Minnesota	Swift	6,400	6,200	25.8	160,100	17.40
Sugarbeets	2008	Minnesota	Traverse	6,600	6,200	22.3	138,500	17.00
Sugarbeets	2008	Minnesota	Wilkin	45,100	26,700	25.4	653,000	16.30
Sugarbeets	2008	Minnesota	Yellow Medicine	3,200	3,100	21.5	66,600	17.00
Sugarbeets	2008	Minnesota	D40 Combined Counties	900	800	20.9	16,700	17.16
Sugarbeets	2008	Minnesota	D40 West Central	116,000	92,000	23.7	2,182,300	16.80
Sugarbeets	2008	Minnesota	Kandiyohi	14,500	14,400	26.2	376,600	17.20
Sugarbeets	2008	Minnesota	McLeod	1,600	1,400	24.4	34,100	16.70
Sugarbeets	2008	Minnesota	Renville	32,700	32,500	25.2	820,300	17.00
Sugarbeets	2008	Minnesota	Sibley	3,200	3,200	24.6	79,700	16.60
Sugarbeets	2008	Minnesota	Stearns	2,100	2,000	22.4	44,700	17.30
Sugarbeets	2008	Minnesota	D50 Combined Counties	3,500	3,400	25.6	90,500	17.00
Sugarbeets	2008	Minnesota	D50 Central	57,500	56,900	25.4	1,445,900	17.00
Sugarbeets	2008	Minnesota	Lyon	400	400	15.3	6,100	17.80
Sugarbeets	2008	Minnesota	Redwood	3,600	3,400	22.6	76,800	16.70
Sugarbeets	2008	Minnesota	D70 Combined Counties	300	200	15.5	3,700	17.20
Sugarbeets	2008	Minnesota	D70 Southwest	4,200	4,000	21.7	86,800	16.80
Sugarbeets	2008	Minnesota	D99 Combined Districts	600	600	25.8	15,300	16.56
Sugarbeets	**2008**	**Minnesota**	**State Total**	**440,000**	**399,000**	**24.7**	**9,855,000**	**17.25**
Sugarbeets	2008	Montana	D30 Combined Counties	6,900	6,900	24.9	171,900	16.92
Sugarbeets	2008	Montana	D30 Northeast	6,900	6,900	24.6	171,900	16.92
Sugarbeets	2008	Montana	Big Horn	9,100	8,800	28.2	253,000	16.91
Sugarbeets	2008	Montana	Carbon	3,600	3,500	24.0	82,900	16.84
Sugarbeets	2008	Montana	Yellowstone	6,700	6,000	25.9	155,200	16.96
Sugarbeets	2008	Montana	D80 Combined Counties	3,600	3,500	28.8	100,700	17.16
Sugarbeets	2008	Montana	D80 South Central	22,800	21,200	27.2	592,500	16.96
Sugarbeets	2008	Montana	Rosebud	2,000	2,000	29.2	58,300	17.36
Sugarbeets	2008	Montana	D90 Southeast	2,000	2,000	29.2	58,300	17.36
Sugarbeets	**2008**	**Montana**	**State Total**	**31,700**	**30,700**	**26.8**	**823,000**	**17.27**
Sugarbeets	2008	Nebraska	Banner	700	400	20.8	8,300	17.17
Sugarbeets	2008	Nebraska	Box Butte	18,900	17,300	22.6	388,600	17.10
Sugarbeets	2008	Nebraska	Cheyenne	1,900	1,100	24.8	27,300	17.22
Sugarbeets	2008	Nebraska	Kimball	2,800	2,600	21.3	55,400	17.36
Sugarbeets	2008	Nebraska	Morrill	5,800	4,100	22.7	93,100	16.34
Sugarbeets	2008	Nebraska	Scotts Bluff	7,800	5,700	23.1	131,900	16.31
Sugarbeets	2008	Nebraska	Sheridan	2,500	2,400	22.1	53,100	16.85
Sugarbeets	2008	Nebraska	D10 Combined Counties	700	700	21.6	15,100	17.05
Sugarbeets	2008	Nebraska	D10 Northwest	41,100	34,300	22.5	772,500	16.94
Sugarbeets	2008	Nebraska	Chase	700	600	17.5	10,500	16.04
Sugarbeets	2008	Nebraska	Keith	2,600	1,200	25.0	45,000	17.32
Sugarbeets	2008	Nebraska	Perkins	800	600	24.8	14,700	17.05
Sugarbeets	2008	Nebraska	D70 Southwest	4,100	3,000	23.4	70,200	17.01
Sugarbeets	**2008**	**Nebraska**	**State Total**	**45,200**	**37,300**	**22.6**	**843,000**	**16.94**
Sugarbeets	2008	North Dakota	Williams	2,100	1,900	22.6	43,000	17.50
Sugarbeets	2008	North Dakota	D10 Northwest	2,100	1,900	22.6	43,000	17.50
Sugarbeets	2008	North Dakota	Grand Forks	27,200	27,000	26.7	720,000	17.65
Sugarbeets	2008	North Dakota	Pembina	59,000	58,300	25.6	1,492,500	17.76
Sugarbeets	2008	North Dakota	Walsh	43,800	40,400	26.1	1,055,000	15.07
Sugarbeets	2008	North Dakota	D30 Northeast	127,000	125,700	25.0	3,228,000	17.65
Sugarbeets	2008	North Dakota	McKenzie	6,200	5,800	24.8	144,000	15.18
Sugarbeets	2008	North Dakota	D40 West Central	6,200	5,800	24.8	144,000	15.18
Sugarbeets	2008	North Dakota	Cass	17,000	16,500	25.3	418,000	17.06
Sugarbeets	2008	North Dakota	Steele	400	400	30.0	12,000	16.72
Sugarbeets	2008	North Dakota	Traill	25,200	24,900	26.1	651,000	17.48
Sugarbeets	2008	North Dakota	D60 East Central	43,600	41,800	25.9	1,081,000	17.32
Sugarbeets	2008	North Dakota	Richland	25,800	21,400	25.9	554,000	16.37
Sugarbeets	2008	North Dakota	D90 Combined Counties	400	400	30.0	12,000	16.40
Sugarbeets	2008	North Dakota	D90 Southeast	22,200	21,800	26.0	566,000	16.37
Sugarbeets	**2008**	**North Dakota**	**State Total**	**208,000**	**197,000**	**25.9**	**5,102,000**	**17.58**
Sugarbeets	2008	Oregon	Union	1,500	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	D30 Northeast	1,500	1,400	27.9	39,000	17.32
Sugarbeets	2008	Oregon	Malheur	5,200	4,500	34.7	156,000	16.09
Sugarbeets	2008	Oregon	D80 Southeast	5,200	4,500	34.7	156,000	16.09
Sugarbeets	**2008**	**Oregon**	**State Total**	**6,700**	**5,900**	**33.1**	**195,000**	**16.34**
Sugarbeets	2008	Washington	Benton	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	D20 Central	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Washington	State Total	1,600	1,600	41.9	67,000	16.51
Sugarbeets	2008	Wyoming	Big Horn	8,300	8,100	23.4	189,300	17.46
Sugarbeets	2008	Wyoming	Fremont	1,500	1,500	30.1	33,200	15.00

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Wyoming	Park	10,300	9,900	25.4	251,900	17.69
Sugarbeets	2008	Wyoming	Washakie	5,700	5,600	27.0	148,400	17.40
Sugarbeets	2008	Wyoming	D10 Northwest	25,800	25,000	24.8	612,500	17.56
Sugarbeets	2008	Wyoming	Goshen	1,200	1,100	21.6	23,700	17.04
Sugarbeets	2008	Wyoming	Laramie	500	300	20.7	6,200	17.72
Sugarbeets	2008	Wyoming	Platte	2,200	700	20.4	14,300	17.11
Sugarbeets	2008	Wyoming	D50 Southeast	3,900	2,100	21.0	44,200	17.29
Sugarbeets	**2008**	**Wyoming**	**State Total**	**25,700**	**27,100**	**24.5**	**664,000**	**17.56**
Sugarbeets	2007	California	Fresno	9,200	9,200	30.8	282,000	15.61
Sugarbeets	2007	California	Kern	3,200	3,100	34.2	108,000	15.27
Sugarbeets	2007	California	Kings	1,300	1,300	30.8	40,000	14.83
Sugarbeets	2007	California	Merced	2,200	2,200	29.1	64,000	17.66
Sugarbeets	2007	California	D61 Combined Counties	400	400	35.0	14,000	15.66
Sugarbeets	2007	California	D61 San Joaquin Valley	16,300	16,200	31.3	507,000	15.72
Sugarbeets	2007	California	Imperial	23,700	22,900	41.9	959,000	16.36
Sugarbeets	2007	California	D60 Southern California	23,700	22,900	41.9	959,000	16.36
Sugarbeets	**2007**	**California**	**State Total**	**40,000**	**39,100**	**37.5**	**1,466,000**	**16.15**
Sugarbeets	2007	Colorado	Boulder	600	600	29.2	14,600	15.89
Sugarbeets	2007	Colorado	Larimer	2,400	2,300	24.7	56,900	15.00
Sugarbeets	2007	Colorado	Logan	4,000	3,700	22.7	84,000	15.32
Sugarbeets	2007	Colorado	Morgan	1,600	1,400	26.6	37,200	14.99
Sugarbeets	2007	Colorado	Sedgwick	1,000	800	23.4	18,700	16.26
Sugarbeets	2007	Colorado	Weld	11,800	10,700	28.3	302,500	15.31
Sugarbeets	2007	Colorado	D20 Northeast	21,300	19,400	26.5	514,000	15.42
Sugarbeets	2007	Colorado	Kit Carson	700	700	24.4	17,100	15.72
Sugarbeets	2007	Colorado	Phillips	3,300	3,000	18.9	56,700	16.21
Sugarbeets	2007	Colorado	Washington	700	600	26.2	15,100	15.08
Sugarbeets	2007	Colorado	Yuma	5,700	5,300	29.0	153,500	15.38
Sugarbeets	2007	Colorado	D60 Combined Counties	300	200	23.0	4,600	15.25
Sugarbeets	2007	Colorado	D80 East Central	10,700	9,800	25.6	251,000	15.60
Sugarbeets	**2007**	**Colorado**	**State Total**	**32,000**	**29,200**	**26.2**	**765,000**	**15.48**
Sugarbeets	2007	Idaho	Ada	2,100	2,000	33.5	67,000	15.50
Sugarbeets	2007	Idaho	Canyon	11,100	10,900	36.8	401,000	15.50
Sugarbeets	2007	Idaho	Elmore	8,800	8,700	30.9	269,000	16.63
Sugarbeets	2007	Idaho	Owyhee	3,200	3,200	34.1	109,000	16.04
Sugarbeets	2007	Idaho	Washington	1,400	1,300	35.4	46,000	15.49
Sugarbeets	2007	Idaho	D70 Combined Counties	1,400	1,400	34.3	48,000	16.23
Sugarbeets	2007	Idaho	D70 Southwest	28,000	27,500	34.2	940,000	15.89
Sugarbeets	2007	Idaho	Blaine	600	600	33.3	20,000	15.97
Sugarbeets	2007	Idaho	Cassia	31,700	31,600	35.6	1,125,000	15.41
Sugarbeets	2007	Idaho	Gooding	1,400	1,300	34.6	45,000	15.68
Sugarbeets	2007	Idaho	Jerome	12,700	12,500	34.5	431,000	15.50
Sugarbeets	2007	Idaho	Lincoln	6,200	6,100	30.7	187,000	16.48
Sugarbeets	2007	Idaho	Minidoka	42,300	41,900	33.2	1,391,000	15.19
Sugarbeets	2007	Idaho	Twin Falls	10,100	10,000	34.1	341,000	15.20
Sugarbeets	2007	Idaho	D80 South Central	105,000	104,000	34.0	3,540,000	15.31
Sugarbeets	2007	Idaho	Bingham	22,900	22,700	35.8	812,000	15.95
Sugarbeets	2007	Idaho	Power	13,100	12,800	35.4	453,000	15.85
Sugarbeets	2007	Idaho	D90 East	36,000	35,500	35.6	1,265,000	15.91
Sugarbeets	**2007**	**Idaho**	**State Total**	**169,000**	**167,000**	**34.4**	**5,745,000**	**15.15**
Sugarbeets	2007	Michigan	Gladwin	1,000	1,000	17.0	17,000	16.50
Sugarbeets	2007	Michigan	Gratiot	11,200	11,000	21.1	232,000	15.10
Sugarbeets	2007	Michigan	Isabella	600	600	20.0	12,000	17.60
Sugarbeets	2007	Michigan	Midland	2,800	2,800	20.4	57,000	15.10
Sugarbeets	2007	Michigan	Montcalm	600	500	22.0	11,000	17.70
Sugarbeets	2007	Michigan	D60 Central	16,000	15,800	20.7	327,000	15.10
Sugarbeets	2007	Michigan	Arenac	3,600	3,600	19.4	70,000	15.90
Sugarbeets	2007	Michigan	Bay	14,800	14,700	20.6	303,000	17.80
Sugarbeets	2007	Michigan	Huron	52,700	52,600	24.9	1,310,000	15.10
Sugarbeets	2007	Michigan	Saginaw	16,100	16,000	24.7	395,000	17.60
Sugarbeets	2007	Michigan	Sanilac	20,600	20,500	22.1	453,000	15.50
Sugarbeets	2007	Michigan	Tuscola	20,000	19,900	25.6	509,000	15.10
Sugarbeets	2007	Michigan	D80 East Central	125,000	127,300	25.9	3,640,000	15.10
Sugarbeets	2007	Michigan	Clinton	2,250	2,250	20.0	45,000	17.00
Sugarbeets	2007	Michigan	Ionia	500	500	22.0	11,000	17.60
Sugarbeets	2007	Michigan	Shiawassee	750	750	18.7	14,000	17.20
Sugarbeets	2007	Michigan	D90 South Central	3,500	3,500	20.0	70,000	17.10
Sugarbeets	2007	Michigan	Lapeer	1,000	1,000	23.0	23,000	15.30
Sugarbeets	2007	Michigan	D60 Combined Counties	1,000	1,000	20.0	20,000	15.40
Sugarbeets	2007	Michigan	D90 Southeast	2,000	2,000	21.5	43,000	15.30
Sugarbeets	2007	Michigan	D98 Combined Districts	500	400	17.5	7,000	17.90
Sugarbeets	**2007**	**Michigan**	**State Total**	**150,000**	**149,000**	**23.4**	**3,487,000**	**16.10**
Sugarbeets	2007	Minnesota	Becker	11,000	10,900	24.8	257,000	17.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Wyoming	Park	10,300	9,900	25.4	251,900	17.69
Sugarbeets	2008	Wyoming	Washakie	5,700	5,500	27.0	148,400	17.40
Sugarbeets	2008	Wyoming	D10 Northwest	25,800	25,000	24.8	619,500	17.58
Sugarbeets	2008	Wyoming	Goshen	1,200	1,100	21.5	23,700	17.04
Sugarbeets	2008	Wyoming	Laramie	500	300	20.7	6,200	17.72
Sugarbeets	2008	Wyoming	Platte	2,200	700	20.4	14,300	17.11
Sugarbeets	2008	Wyoming	D60 Southeast	3,900	2,100	21.0	44,200	17.29
Sugarbeets	**2008**	**Wyoming**	**State Total**	**29,700**	**27,100**	**24.5**	**664,000**	**17.56**
Sugarbeets	2007	California	Fresno	9,200	9,200	30.8	283,000	15.61
Sugarbeets	2007	California	Kern	3,200	3,100	34.2	106,000	15.27
Sugarbeets	2007	California	Kings	1,300	1,300	30.8	40,000	14.83
Sugarbeets	2007	California	Merced	2,200	2,200	29.1	64,000	17.66
Sugarbeets	2007	California	D21 Combined Counties	400	400	35.0	14,000	15.66
Sugarbeets	2007	California	D61 San Joaquin Valley	16,300	16,200	31.3	507,000	15.72
Sugarbeets	2007	California	Imperial	23,700	22,900	41.9	959,000	16.38
Sugarbeets	2007	California	D80 Southern California	23,700	22,900	41.9	959,000	16.38
Sugarbeets	**2007**	**California**	**State Total**	**40,000**	**39,100**	**37.5**	**1,466,000**	**16.15**
Sugarbeets	2007	Colorado	Boulder	500	500	29.2	14,600	15.89
Sugarbeets	2007	Colorado	Larimer	2,400	2,300	24.7	56,900	16.00
Sugarbeets	2007	Colorado	Logan	4,000	3,700	22.7	84,000	15.32
Sugarbeets	2007	Colorado	Morgan	1,600	1,400	26.6	37,200	14.99
Sugarbeets	2007	Colorado	Sedgwick	1,000	800	23.4	18,700	16.28
Sugarbeets	2007	Colorado	Weld	11,800	10,700	28.3	302,800	15.31
Sugarbeets	2007	Colorado	D30 Northeast	21,300	19,400	26.5	514,000	15.42
Sugarbeets	2007	Colorado	Kit Carson	700	700	24.4	17,100	15.72
Sugarbeets	2007	Colorado	Phillips	3,800	3,000	19.9	59,700	16.21
Sugarbeets	2007	Colorado	Washington	700	600	26.8	16,100	15.08
Sugarbeets	2007	Colorado	Yuma	5,700	5,300	29.0	153,500	15.36
Sugarbeets	2007	Colorado	D50 Combined Counties	300	200	23.0	4,600	15.25
Sugarbeets	2007	Colorado	D60 East Central	10,700	9,800	25.6	251,000	15.60
Sugarbeets	**2007**	**Colorado**	**State Total**	**32,000**	**29,200**	**26.2**	**765,000**	**15.48**
Sugarbeets	2007	Idaho	Ada	2,100	2,000	33.5	67,000	15.50
Sugarbeets	2007	Idaho	Canyon	11,100	10,600	38.8	401,000	15.50
Sugarbeets	2007	Idaho	Elmore	6,800	6,700	30.9	282,000	16.53
Sugarbeets	2007	Idaho	Owyhee	3,200	3,200	34.1	109,000	16.04
Sugarbeets	2007	Idaho	Washington	1,400	1,300	35.4	46,000	15.49
Sugarbeets	2007	Idaho	D70 Combined Counties	1,400	1,400	34.3	48,000	16.23
Sugarbeets	2007	Idaho	D70 Southwest	28,000	27,600	34.2	940,000	15.89
Sugarbeets	2007	Idaho	Blaine	600	600	33.3	20,000	15.97
Sugarbeets	2007	Idaho	Cassia	31,700	31,600	35.6	1,125,000	16.41
Sugarbeets	2007	Idaho	Gooding	1,400	1,300	34.6	45,000	15.68
Sugarbeets	2007	Idaho	Jerome	12,700	12,500	34.5	431,000	16.50
Sugarbeets	2007	Idaho	Lincoln	6,200	6,100	30.7	187,000	16.48
Sugarbeets	2007	Idaho	Minidoka	42,300	41,900	33.2	1,391,000	16.19
Sugarbeets	2007	Idaho	Twin Falls	10,100	10,000	34.1	341,000	16.20
Sugarbeets	2007	Idaho	D80 South Central	105,000	104,000	34.0	3,540,000	16.31
Sugarbeets	2007	Idaho	Bingham	22,900	22,700	35.8	812,000	15.95
Sugarbeets	2007	Idaho	Power	13,100	12,800	35.4	453,000	15.89
Sugarbeets	2007	Idaho	D90 East	36,000	35,500	35.6	1,265,000	15.91
Sugarbeets	**2007**	**Idaho**	**State Total**	**169,000**	**167,000**	**34.4**	**5,745,000**	**16.15**
Sugarbeets	2007	Michigan	Gladwin	1,000	1,000	17.0	17,000	16.60
Sugarbeets	2007	Michigan	Gratiot	11,200	11,000	21.1	232,000	16.10
Sugarbeets	2007	Michigan	Isabella	600	600	20.0	10,000	17.60
Sugarbeets	2007	Michigan	Midland	2,800	2,800	20.4	57,000	16.10
Sugarbeets	2007	Michigan	Montcalm	500	500	22.0	11,000	17.70
Sugarbeets	2007	Michigan	D50 Central	16,000	15,800	20.7	327,000	16.10
Sugarbeets	2007	Michigan	Arenac	3,800	3,600	19.4	70,000	16.90
Sugarbeets	2007	Michigan	Bay	14,800	14,700	20.6	303,000	17.80
Sugarbeets	2007	Michigan	Huron	52,700	52,600	24.9	1,310,000	16.10
Sugarbeets	2007	Michigan	Saginaw	16,100	16,000	24.7	395,000	17.80
Sugarbeets	2007	Michigan	Sanilac	20,800	20,500	22.1	453,000	16.50
Sugarbeets	2007	Michigan	Tuscola	20,000	19,900	25.6	509,000	16.10
Sugarbeets	2007	Michigan	D60 East Central	128,000	127,300	23.9	3,040,000	16.10
Sugarbeets	2007	Michigan	Clinton	2,250	2,250	20.0	45,000	17.00
Sugarbeets	2007	Michigan	Ionia	500	500	22.0	11,000	17.60
Sugarbeets	2007	Michigan	Shiawassee	750	750	18.7	14,000	17.20
Sugarbeets	2007	Michigan	D80 South Central	3,500	3,500	20.0	70,000	17.10
Sugarbeets	2007	Michigan	Lapeer	1,000	1,000	23.0	23,000	16.30
Sugarbeets	2007	Michigan	D90 Combined Counties	1,000	1,000	20.0	20,000	16.40
Sugarbeets	2007	Michigan	D90 Southeast	2,000	2,000	21.5	43,000	16.30
Sugarbeets	2007	Michigan	D98 Combined Districts	500	400	17.5	7,000	17.90
Sugarbeets	**2007**	**Michigan**	**State Total**	**150,000**	**149,000**	**23.4**	**3,487,000**	**16.10**
Sugarbeets	2007	Minnesota	Becker	11,000	10,900	24.5	267,000	17.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Wyoming	Park	10,300	9,900	25.4	251,900	17.69
Sugarbeets	2008	Wyoming	Washakie	5,700	5,500	27.0	148,400	17.40
Sugarbeets	2008	Wyoming	D10 Northwest	25,800	25,000	24.8	619,500	17.58
Sugarbeets	2008	Wyoming	Goshen	1,200	1,100	21.5	23,700	17.84
Sugarbeets	2008	Wyoming	Laramie	500	300	20.7	6,200	17.72
Sugarbeets	2008	Wyoming	Platte	2,200	700	20.4	14,300	17.11
Sugarbeets	2008	Wyoming	D50 Southeast	3,900	2,100	21.0	44,200	17.29
Sugarbeets	**2008**	**Wyoming**	**State Total**	**29,700**	**27,100**	**24.5**	**664,000**	**17.56**
Sugarbeets	2007	California	Fresno	9,200	9,200	30.8	283,000	15.61
Sugarbeets	2007	California	Kern	3,200	3,100	34.2	106,000	15.27
Sugarbeets	2007	California	Kings	1,300	1,300	30.8	40,000	14.85
Sugarbeets	2007	California	Merced	2,200	2,200	29.1	64,000	17.68
Sugarbeets	2007	California	D61 Combined Counties	400	400	35.0	14,000	15.65
Sugarbeets	2007	California	D61 San Joaquin Valley	16,300	16,200	31.3	507,000	15.72
Sugarbeets	2007	California	Imperial	23,700	22,900	41.9	959,000	16.38
Sugarbeets	2007	California	D20 Southern California	23,700	22,900	41.9	959,000	16.38
Sugarbeets	**2007**	**California**	**State Total**	**40,000**	**39,100**	**37.5**	**1,466,000**	**16.15**
Sugarbeets	2007	Colorado	Boulder	500	500	29.2	14,600	15.69
Sugarbeets	2007	Colorado	Larimer	2,400	2,300	24.7	56,900	16.00
Sugarbeets	2007	Colorado	Logan	4,000	3,700	22.7	84,000	15.33
Sugarbeets	2007	Colorado	Morgan	1,800	1,400	26.6	37,200	14.99
Sugarbeets	2007	Colorado	Sedgwick	1,000	800	23.4	18,700	16.28
Sugarbeets	2007	Colorado	Weld	11,800	10,700	28.3	302,500	15.31
Sugarbeets	2007	Colorado	D20 Northeast	21,300	19,400	26.5	514,000	15.42
Sugarbeets	2007	Colorado	Kit Carson	700	700	24.4	17,100	15.72
Sugarbeets	2007	Colorado	Phillips	3,300	3,000	19.9	59,700	16.21
Sugarbeets	2007	Colorado	Washington	700	600	26.8	16,100	15.08
Sugarbeets	2007	Colorado	Yuma	5,700	5,300	29.0	153,500	15.38
Sugarbeets	2007	Colorado	D60 Combined Counties	300	200	23.0	4,600	16.25
Sugarbeets	2007	Colorado	D60 East Central	10,700	9,800	25.6	251,000	15.60
Sugarbeets	**2007**	**Colorado**	**State Total**	**32,000**	**29,200**	**26.2**	**765,000**	**15.48**
Sugarbeets	2007	Idaho	Ada	2,100	2,000	33.5	67,000	15.50
Sugarbeets	2007	Idaho	Canyon	11,100	10,900	36.8	401,000	15.50
Sugarbeets	2007	Idaho	Elmore	5,800	8,700	30.9	269,000	16.53
Sugarbeets	2007	Idaho	Owyhee	3,200	3,200	34.1	109,000	16.04
Sugarbeets	2007	Idaho	Washington	1,400	1,300	35.4	46,000	15.49
Sugarbeets	2007	Idaho	D70 Combined Counties	1,400	1,400	34.3	48,000	16.23
Sugarbeets	2007	Idaho	D70 Southwest	28,000	27,800	34.2	949,000	15.80
Sugarbeets	2007	Idaho	Blaine	600	600	33.3	20,000	15.97
Sugarbeets	2007	Idaho	Cassia	31,700	31,600	35.6	1,125,000	16.41
Sugarbeets	2007	Idaho	Gooding	1,400	1,300	34.6	45,000	15.68
Sugarbeets	2007	Idaho	Jerome	12,700	12,500	34.5	431,000	16.50
Sugarbeets	2007	Idaho	Lincoln	6,200	6,100	30.7	187,000	16.49
Sugarbeets	2007	Idaho	Minidoka	42,300	41,900	33.2	1,391,000	16.19
Sugarbeets	2007	Idaho	Twin Falls	10,100	10,000	34.1	341,000	16.20
Sugarbeets	2007	Idaho	D80 South Central	105,000	104,000	34.0	3,540,000	16.31
Sugarbeets	2007	Idaho	Bingham	22,900	22,700	35.8	812,000	15.85
Sugarbeets	2007	Idaho	Power	13,100	12,800	35.4	453,000	15.85
Sugarbeets	2007	Idaho	D90 East	36,000	35,500	35.6	1,265,000	15.91
Sugarbeets	**2007**	**Idaho**	**State Total**	**169,000**	**167,000**	**34.4**	**5,745,000**	**16.15**
Sugarbeets	2007	Michigan	Gladwin	1,000	1,000	17.0	17,000	15.80
Sugarbeets	2007	Michigan	Gratiot	11,200	11,000	21.1	232,000	16.10
Sugarbeets	2007	Michigan	Isabella	500	500	20.0	10,000	17.60
Sugarbeets	2007	Michigan	Midland	2,800	2,800	20.4	57,000	16.10
Sugarbeets	2007	Michigan	Montcalm	500	500	22.0	11,000	17.70
Sugarbeets	2007	Michigan	D50 Central	16,000	15,800	20.7	327,000	16.10
Sugarbeets	2007	Michigan	Arenac	3,600	3,600	19.4	70,000	16.90
Sugarbeets	2007	Michigan	Bay	14,800	14,700	20.6	303,000	17.60
Sugarbeets	2007	Michigan	Huron	52,700	52,600	24.9	1,310,000	16.10
Sugarbeets	2007	Michigan	Saginaw	16,100	16,000	24.7	395,000	17.60
Sugarbeets	2007	Michigan	Sanilac	20,600	20,600	22.1	453,000	15.60
Sugarbeets	2007	Michigan	Tuscola	20,000	19,900	25.6	509,000	15.10
Sugarbeets	2007	Michigan	D60 East Central	128,000	127,300	23.9	3,040,000	16.10
Sugarbeets	2007	Michigan	Clinton	2,250	2,250	20.0	45,000	17.60
Sugarbeets	2007	Michigan	Ionia	500	500	22.0	11,000	17.60
Sugarbeets	2007	Michigan	Shiawassee	750	750	18.7	14,000	17.20
Sugarbeets	2007	Michigan	D80 South Central	3,500	3,500	20.0	70,000	17.10
Sugarbeets	2007	Michigan	Lapeer	1,000	1,000	23.0	23,000	15.30
Sugarbeets	2007	Michigan	D90 Combined Counties	1,000	1,000	20.0	20,000	15.40
Sugarbeets	2007	Michigan	D90 Southeast	2,000	2,000	21.5	43,000	15.30
Sugarbeets	2007	Michigan	D98 Combined Districts	500	400	17.5	7,000	17.90
Sugarbeets	**2007**	**Michigan**	**State Total**	**150,000**	**149,000**	**23.4**	**3,487,000**	**18.10**
Sugarbeets	2007	Minnesota	Becker	11,000	10,900	24.5	267,000	17.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2008	Wyoming	Park	10,300	9,900	25.4	251,900	17.69
Sugarbeets	2008	Wyoming	Washakie	5,700	5,300	27.0	148,400	17.40
Sugarbeets	2008	Wyoming	D10 Northwest	25,800	25,000	24.8	619,500	17.58
Sugarbeets	2008	Wyoming	Goshen	1,200	1,100	21.5	23,700	17.64
Sugarbeets	2008	Wyoming	Laramie	500	300	20.7	6,200	17.72
Sugarbeets	2008	Wyoming	Platte	2,200	700	20.4	14,300	17.11
Sugarbeets	2008	Wyoming	D60 Southeast	3,900	2,100	21.0	44,200	17.29
Sugarbeets	**2008**	**Wyoming**	**State Total**	**29,700**	**27,100**	**24.5**	**664,000**	**17.56**
Sugarbeets	2007	California	Fresno	9,200	9,200	30.3	353,000	15.61
Sugarbeets	2007	California	Kern	3,200	3,100	34.2	106,000	15.27
Sugarbeets	2007	California	Kings	1,300	1,300	30.8	40,000	14.83
Sugarbeets	2007	California	Merced	2,200	2,200	29.1	64,000	17.66
Sugarbeets	2007	California	D61 Combined Counties	400	400	35.0	14,000	15.66
Sugarbeets	2007	California	D51 San Joaquin Valley	16,300	16,200	31.3	507,000	15.72
Sugarbeets	2007	California	Imperial	23,700	22,900	41.9	952,000	16.38
Sugarbeets	2007	California	D60 Southern California	23,700	22,900	41.9	952,000	16.38
Sugarbeets	**2007**	**California**	**State Total**	**40,000**	**39,100**	**37.5**	**1,466,000**	**16.15**
Sugarbeets	2007	Colorado	Boulder	500	500	29.2	14,600	15.69
Sugarbeets	2007	Colorado	Larimer	2,400	2,300	24.7	56,900	16.00
Sugarbeets	2007	Colorado	Logan	4,000	3,700	22.7	84,000	15.32
Sugarbeets	2007	Colorado	Morgan	1,600	1,400	26.6	37,200	14.89
Sugarbeets	2007	Colorado	Sedgwick	1,000	800	23.4	18,700	16.26
Sugarbeets	2007	Colorado	Weld	11,800	10,700	28.3	302,800	15.31
Sugarbeets	2007	Colorado	D30 Northeast	21,300	19,400	26.5	514,000	15.42
Sugarbeets	2007	Colorado	Kit Carson	700	700	24.4	17,100	15.72
Sugarbeets	2007	Colorado	Phillips	3,300	3,000	19.9	59,700	16.21
Sugarbeets	2007	Colorado	Washington	700	600	25.8	16,100	15.08
Sugarbeets	2007	Colorado	Yuma	5,700	5,300	29.0	153,500	15.38
Sugarbeets	2007	Colorado	D60 Combined Counties	300	200	23.0	4,600	16.25
Sugarbeets	2007	Colorado	D60 East Central	10,700	9,800	25.6	251,000	15.60
Sugarbeets	**2007**	**Colorado**	**State Total**	**32,000**	**29,200**	**26.2**	**765,000**	**15.48**
Sugarbeets	2007	Idaho	Ada	2,100	2,000	33.5	67,000	15.50
Sugarbeets	2007	Idaho	Canyon	11,100	10,900	36.8	401,000	15.50
Sugarbeets	2007	Idaho	Elmore	9,800	8,700	30.9	269,000	16.63
Sugarbeets	2007	Idaho	Owyhee	3,200	3,200	34.1	109,000	16.04
Sugarbeets	2007	Idaho	Washington	1,400	1,300	35.4	46,000	15.49
Sugarbeets	2007	Idaho	D70 Combined Counties	1,400	1,400	34.3	48,000	16.23
Sugarbeets	2007	Idaho	D70 Southwest	25,000	27,500	34.2	940,000	15.89
Sugarbeets	2007	Idaho	Blaine	600	600	33.3	20,000	15.97
Sugarbeets	2007	Idaho	Cassia	31,700	31,600	35.6	1,125,000	15.41
Sugarbeets	2007	Idaho	Gooding	1,400	1,300	34.6	45,000	15.68
Sugarbeets	2007	Idaho	Jerome	12,700	12,500	34.5	431,000	15.50
Sugarbeets	2007	Idaho	Lincoln	6,200	6,100	30.7	187,000	16.48
Sugarbeets	2007	Idaho	Minidoka	42,300	41,900	33.2	1,391,000	16.19
Sugarbeets	2007	Idaho	Twin Falls	10,100	10,000	34.1	341,000	16.20
Sugarbeets	2007	Idaho	D80 South Central	105,000	104,000	34.0	3,540,000	16.31
Sugarbeets	2007	Idaho	Bingham	22,900	22,700	35.8	812,000	15.95
Sugarbeets	2007	Idaho	Power	13,100	12,800	35.4	453,000	15.85
Sugarbeets	2007	Idaho	D90 East	36,000	35,500	35.6	1,265,000	15.91
Sugarbeets	**2007**	**Idaho**	**State Total**	**169,000**	**167,000**	**34.4**	**5,745,000**	**16.15**
Sugarbeets	2007	Michigan	Gladwin	1,000	1,000	17.0	17,000	16.50
Sugarbeets	2007	Michigan	Gratiot	11,200	11,000	21.1	232,000	16.10
Sugarbeets	2007	Michigan	Isabella	500	500	20.0	10,000	17.60
Sugarbeets	2007	Michigan	Midland	2,800	2,800	20.4	57,000	16.10
Sugarbeets	2007	Michigan	Montcalm	500	500	22.0	11,000	17.70
Sugarbeets	2007	Michigan	D50 Central	16,000	15,800	20.7	327,000	16.10
Sugarbeets	2007	Michigan	Arenac	3,800	3,800	19.4	70,000	15.90
Sugarbeets	2007	Michigan	Bay	14,800	14,700	20.6	303,000	17.60
Sugarbeets	2007	Michigan	Huron	52,700	52,600	24.9	1,310,000	15.10
Sugarbeets	2007	Michigan	Saginaw	16,100	16,000	24.7	395,000	17.80
Sugarbeets	2007	Michigan	Sanilac	20,600	20,500	22.1	453,000	15.50
Sugarbeets	2007	Michigan	Tuscola	20,000	19,900	25.6	509,000	16.10
Sugarbeets	2007	Michigan	D60 East Central	135,000	127,300	23.6	3,040,000	16.10
Sugarbeets	2007	Michigan	Clinton	2,250	2,250	20.0	45,000	17.60
Sugarbeets	2007	Michigan	Ionia	500	500	22.0	11,000	17.60
Sugarbeets	2007	Michigan	Shiawassee	750	750	15.7	14,000	17.20
Sugarbeets	2007	Michigan	D80 South Central	3,500	3,500	20.0	70,000	17.10
Sugarbeets	2007	Michigan	Lapeer	1,000	1,000	23.0	23,000	15.30
Sugarbeets	2007	Michigan	D90 Combined Counties	1,000	1,000	20.0	20,000	15.40
Sugarbeets	2007	Michigan	D90 Southeast	2,000	2,000	21.5	43,000	15.30
Sugarbeets	2007	Michigan	D98 Combined Districts	500	400	17.5	7,000	17.90
Sugarbeets	**2007**	**Michigan**	**State Total**	**150,000**	**149,000**	**23.4**	**3,487,000**	**16.10**
Sugarbeets	2007	Minnesota	Becker	11,000	10,900	24.5	267,000	17.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	Minnesota	Clay	52,200	51,200	21.6	1,106,400	17.10
Sugarbeets	2007	Minnesota	Kittson	38,900	38,600	20.4	787,400	16.90
Sugarbeets	2007	Minnesota	Mahnomen	5,500	5,500	23.9	131,500	17.80
Sugarbeets	2007	Minnesota	Marshall	46,300	45,700	22.9	1,046,000	16.90
Sugarbeets	2007	Minnesota	Norman	46,300	47,700	24.3	1,159,400	17.70
Sugarbeets	2007	Minnesota	Polk	100,600	99,800	25.6	2,553,400	16.20
Sugarbeets	2007	Minnesota	D10 Combined Counties	1,700	1,600	25.4	40,650	17.90
Sugarbeets	2007	Minnesota	D10 Northwest	302,500	299,000	23.6	7,051,500	16.90
Sugarbeets	2007	Minnesota	Chippewa	30,600	30,600	26.0	794,700	16.20
Sugarbeets	2007	Minnesota	Grant	10,300	10,200	19.9	202,300	16.90
Sugarbeets	2007	Minnesota	Otter Tail	2,300	2,300	18.9	43,500	17.20
Sugarbeets	2007	Minnesota	Pope	2,600	2,600	26.9	69,300	16.40
Sugarbeets	2007	Minnesota	Stevens	5,100	5,100	27.2	138,800	16.50
Sugarbeets	2007	Minnesota	Swift	9,200	9,100	25.8	152,300	16.50
Sugarbeets	2007	Minnesota	Traverse	6,500	6,400	20.8	132,900	17.20
Sugarbeets	2007	Minnesota	Wilkin	50,600	49,500	20.1	994,900	17.80
Sugarbeets	2007	Minnesota	Yellow Medicine	4,000	4,000	27.6	110,400	16.20
Sugarbeets	2007	Minnesota	D40 Combined Counties	900	900	23.4	21,100	17.00
Sugarbeets	2007	Minnesota	D40 West Central	119,100	117,700	22.6	2,662,200	17.00
Sugarbeets	2007	Minnesota	Kandiyohi	14,400	14,400	26.3	378,000	16.30
Sugarbeets	2007	Minnesota	McLeod	2,300	2,300	27.0	62,000	16.00
Sugarbeets	2007	Minnesota	Renville	35,400	35,300	27.4	966,600	15.90
Sugarbeets	2007	Minnesota	Sibley	2,100	2,100	29.0	60,900	15.60
Sugarbeets	2007	Minnesota	Stearns	2,500	2,500	24.1	60,300	16.20
Sugarbeets	2007	Minnesota	D50 Combined Counties	2,000	2,000	27.4	54,700	16.80
Sugarbeets	2007	Minnesota	D60 Central	58,700	58,600	27.0	1,582,700	16.00
Sugarbeets	2007	Minnesota	Redwood	4,600	4,600	27.1	124,500	15.70
Sugarbeets	2007	Minnesota	D70 Combined Counties	500	500	20.0	10,000	16.20
Sugarbeets	2007	Minnesota	D70 Southwest	5,100	5,100	26.4	134,500	15.80
Sugarbeets	2007	Minnesota	D98 Combined Districts	600	600	25.0	15,000	16.00
Sugarbeets	**2007**	**Minnesota**	**State Total**	**486,000**	**481,000**	**23.8**	**11,446,000**	**17.50**
Sugarbeets	2007	Montana	Dawson	2,360	2,360	22.7	53,500	17.84
Sugarbeets	2007	Montana	Richland	13,900	13,840	24.0	331,500	15.10
Sugarbeets	2007	Montana	D30 Combined Counties	1,930	1,930	22.2	42,800	17.94
Sugarbeets	2007	Montana	D30 Northeast	18,190	18,130	23.6	427,500	16.05
Sugarbeets	2007	Montana	Big Horn	9,670	9,670	26.6	257,000	15.49
Sugarbeets	2007	Montana	Carbon	3,550	3,530	25.6	90,450	16.31
Sugarbeets	2007	Montana	Treasure	3,320	3,320	27.8	92,300	15.37
Sugarbeets	2007	Montana	Yellowstone	7,640	7,430	22.9	170,900	15.94
Sugarbeets	2007	Montana	D80 Combined Counties	180	120	31.7	3,700	16.00
Sugarbeets	2007	Montana	D80 South Central	24,390	24,130	25.2	615,300	15.71
Sugarbeets	2007	Montana	Custer	650	650	25.5	16,600	17.21
Sugarbeets	2007	Montana	Prairie	1,760	1,760	23.6	42,000	16.07
Sugarbeets	2007	Montana	D90 Combined Counties	2,490	2,310	25.7	59,300	15.53
Sugarbeets	2007	Montana	D90 Southeast	4,920	4,740	24.9	117,900	16.68
Sugarbeets	**2007**	**Montana**	**State Total**	**47,500**	**47,000**	**24.7**	**1,161,000**	**16.67**
Sugarbeets	2007	Nebraska	Box Butte	20,100	19,900	23.2	474,300	17.16
Sugarbeets	2007	Nebraska	Cheyenne	1,800	1,800	23.9	43,100	16.60
Sugarbeets	2007	Nebraska	Deuel	600	600	19.3	11,600	16.09
Sugarbeets	2007	Nebraska	Kimball	3,300	3,100	25.3	78,500	16.67
Sugarbeets	2007	Nebraska	Morrill	5,200	4,900	22.8	111,700	15.63
Sugarbeets	2007	Nebraska	Scotts Bluff	7,100	6,800	23.1	156,300	15.58
Sugarbeets	2007	Nebraska	Sheridan	2,900	2,400	23.0	55,200	16.54
Sugarbeets	2007	Nebraska	Sioux	600	500	26.2	13,100	15.79
Sugarbeets	2007	Nebraska	D10 Combined Counties	500	500	21.4	10,700	17.31
Sugarbeets	2007	Nebraska	D10 Northwest	42,000	40,200	23.6	948,500	16.61
Sugarbeets	2007	Nebraska	Chase	2,700	2,500	22.2	55,400	15.51
Sugarbeets	2007	Nebraska	Keith	2,000	1,300	23.2	30,200	16.08
Sugarbeets	2007	Nebraska	Perkins	600	300	29.0	8,900	15.17
Sugarbeets	2007	Nebraska	D70 Southwest	5,600	4,100	22.6	92,600	15.67
Sugarbeets	**2007**	**Nebraska**	**State Total**	**47,500**	**44,300**	**23.5**	**1,041,000**	**16.52**
Sugarbeets	2007	North Dakota	Williams	4,100	4,000	21.0	84,000	16.97
Sugarbeets	2007	North Dakota	D10 Northwest	4,100	4,000	21.0	84,000	16.97
Sugarbeets	2007	North Dakota	Grand Forks	30,900	30,800	25.5	760,000	17.95
Sugarbeets	2007	North Dakota	Pembina	79,100	78,200	22.9	1,791,000	15.25
Sugarbeets	2007	North Dakota	Walsh	44,000	43,100	23.5	1,014,000	15.19
Sugarbeets	2007	North Dakota	D30 Northeast	154,000	151,900	23.6	3,585,000	16.17
Sugarbeets	2007	North Dakota	McKenzie	10,600	10,400	24.7	257,000	15.80
Sugarbeets	2007	North Dakota	D40 West Central	10,600	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	Cass	24,600	23,800	22.6	535,000	17.46
Sugarbeets	2007	North Dakota	Steele	300	300	26.7	8,000	16.53
Sugarbeets	2007	North Dakota	Traill	27,400	26,600	24.1	641,000	17.66
Sugarbeets	2007	North Dakota	D60 East Central	52,300	50,700	23.4	1,184,000	17.56

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	Minnesota	Clay	52,200	51,200	21.6	1,106,400	17.10
Sugarbeets	2007	Minnesota	Kittson	36,900	36,600	20.4	747,400	16.90
Sugarbeets	2007	Minnesota	Mahnomen	5,500	5,200	23.9	131,500	17.80
Sugarbeets	2007	Minnesota	Marshall	46,300	46,700	22.9	1,046,000	15.90
Sugarbeets	2007	Minnesota	Norman	45,300	47,700	24.3	1,158,400	17.70
Sugarbeets	2007	Minnesota	Polk	103,600	99,200	25.8	2,553,400	15.20
Sugarbeets	2007	Minnesota	D10 Combined Counties	1,700	1,600	25.4	40,600	17.00
Sugarbeets	2007	Minnesota	D10 Northwest	302,500	299,000	23.6	7,051,500	16.00
Sugarbeets	2007	Minnesota	Chippewa	30,600	30,600	25.0	764,700	16.20
Sugarbeets	2007	Minnesota	Grant	10,300	10,200	19.8	202,300	16.90
Sugarbeets	2007	Minnesota	Otter Tail	2,300	2,300	18.9	43,500	17.20
Sugarbeets	2007	Minnesota	Pope	2,800	2,800	23.3	65,300	16.40
Sugarbeets	2007	Minnesota	Stevens	5,100	5,100	27.2	138,600	16.50
Sugarbeets	2007	Minnesota	Swift	6,200	6,100	25.5	155,300	16.50
Sugarbeets	2007	Minnesota	Traverse	6,500	6,400	20.8	132,900	17.20
Sugarbeets	2007	Minnesota	Wilkin	50,600	49,200	20.1	984,900	17.80
Sugarbeets	2007	Minnesota	Yellow Medicine	4,000	4,000	27.6	110,400	16.20
Sugarbeets	2007	Minnesota	D40 Combined Counties	900	900	23.4	21,100	17.00
Sugarbeets	2007	Minnesota	D40 West Central	119,100	117,700	22.6	2,662,200	17.00
Sugarbeets	2007	Minnesota	Kandiyohi	14,400	14,400	26.2	378,000	16.30
Sugarbeets	2007	Minnesota	McLeod	2,300	2,300	27.0	62,000	16.00
Sugarbeets	2007	Minnesota	Renville	35,400	36,300	27.4	995,500	15.90
Sugarbeets	2007	Minnesota	Sibley	2,100	2,100	29.0	60,900	15.60
Sugarbeets	2007	Minnesota	Stearns	2,500	2,500	24.1	60,300	16.20
Sugarbeets	2007	Minnesota	D50 Combined Counties	2,000	2,000	27.4	54,700	16.00
Sugarbeets	2007	Minnesota	D60 Central	55,700	58,600	27.0	1,582,700	16.00
Sugarbeets	2007	Minnesota	Redwood	4,600	4,600	27.1	124,500	15.70
Sugarbeets	2007	Minnesota	D70 Combined Counties	600	600	20.0	12,000	16.20
Sugarbeets	2007	Minnesota	D70 Southwest	5,100	5,100	26.4	134,500	15.80
Sugarbeets	2007	Minnesota	D98 Combined Districts	600	600	28.0	16,800	16.00
Sugarbeets	**2007**	**Minnesota**	**State Total**	**486,000**	**481,000**	**23.8**	**11,448,000**	**17.50**
Sugarbeets	2007	Montana	Dawson	2,300	2,300	22.7	53,500	17.84
Sugarbeets	2007	Montana	Richland	13,800	13,840	24.0	331,500	16.10
Sugarbeets	2007	Montana	D30 Combined Counties	1,930	1,930	22.2	42,800	17.94
Sugarbeets	2007	Montana	D30 Northeast	18,130	18,130	23.6	427,600	16.05
Sugarbeets	2007	Montana	Big Horn	9,870	9,870	26.6	257,000	15.48
Sugarbeets	2007	Montana	Carbon	3,560	3,530	25.6	90,400	16.31
Sugarbeets	2007	Montana	Treasure	3,320	3,320	27.8	92,200	15.97
Sugarbeets	2007	Montana	Yellowstone	7,640	7,430	22.9	170,000	16.64
Sugarbeets	2007	Montana	D80 Combined Counties	180	180	31.7	5,700	16.00
Sugarbeets	2007	Montana	D80 South Central	24,300	24,130	25.5	615,300	15.71
Sugarbeets	2007	Montana	Custer	650	650	25.5	16,600	17.21
Sugarbeets	2007	Montana	Prairie	1,780	1,780	23.6	42,000	16.07
Sugarbeets	2007	Montana	D90 Combined Counties	2,490	2,310	25.7	59,300	15.53
Sugarbeets	2007	Montana	D90 Southeast	4,920	4,740	24.9	117,900	16.68
Sugarbeets	**2007**	**Montana**	**State Total**	**47,500**	**47,000**	**24.7**	**1,161,000**	**16.67**
Sugarbeets	2007	Nebraska	Box Butte	20,100	19,900	23.8	474,300	17.16
Sugarbeets	2007	Nebraska	Cheyenne	1,800	1,800	23.9	43,100	16.60
Sugarbeets	2007	Nebraska	Deuel	600	600	19.3	11,600	16.09
Sugarbeets	2007	Nebraska	Kimball	3,300	3,100	25.3	78,500	16.87
Sugarbeets	2007	Nebraska	Morrill	5,200	4,900	22.8	111,700	15.63
Sugarbeets	2007	Nebraska	Scotts Bluff	7,100	6,600	23.1	153,300	16.56
Sugarbeets	2007	Nebraska	Sheridan	2,600	2,400	23.0	55,200	16.54
Sugarbeets	2007	Nebraska	Sioux	600	600	20.3	13,100	15.79
Sugarbeets	2007	Nebraska	D10 Combined Counties	500	500	21.4	10,700	17.31
Sugarbeets	2007	Nebraska	D10 Northwest	42,000	40,200	23.6	948,500	16.61
Sugarbeets	2007	Nebraska	Chase	2,700	2,500	22.2	55,400	15.51
Sugarbeets	2007	Nebraska	Keith	2,000	1,300	23.2	30,200	16.08
Sugarbeets	2007	Nebraska	Perkins	600	300	23.0	6,900	15.17
Sugarbeets	2007	Nebraska	D70 Southwest	5,500	4,100	22.6	92,600	15.67
Sugarbeets	**2007**	**Nebraska**	**State Total**	**47,500**	**44,300**	**23.5**	**1,041,000**	**16.52**
Sugarbeets	2007	North Dakota	Williams	4,100	4,000	21.0	84,000	16.97
Sugarbeets	2007	North Dakota	D10 Northwest	4,100	4,000	21.0	84,000	16.97
Sugarbeets	2007	North Dakota	Grand Forks	30,000	30,600	25.6	780,000	17.95
Sugarbeets	2007	North Dakota	Pembina	79,100	78,200	22.9	1,791,000	16.25
Sugarbeets	2007	North Dakota	Walsh	44,000	43,100	23.5	1,014,000	16.19
Sugarbeets	2007	North Dakota	D30 Northeast	154,000	151,900	23.6	3,585,000	16.17
Sugarbeets	2007	North Dakota	McKenzie	10,500	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	D40 West Central	10,500	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	Cass	24,600	23,800	22.5	535,000	17.46
Sugarbeets	2007	North Dakota	Steele	300	300	26.7	8,000	16.53
Sugarbeets	2007	North Dakota	Traill	27,400	26,600	24.1	641,000	17.66
Sugarbeets	2007	North Dakota	D60 East Central	52,300	50,700	23.4	1,184,000	17.56

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	Minnesota	Clay	52,200	51,200	21.6	1,106,400	17.10
Sugarbeets	2007	Minnesota	Kittson	36,900	36,600	20.4	747,400	15.90
Sugarbeets	2007	Minnesota	Mahnomen	5,600	5,200	23.9	131,500	17.60
Sugarbeets	2007	Minnesota	Marshall	46,300	45,700	22.9	1,046,000	15.80
Sugarbeets	2007	Minnesota	Norman	45,300	47,700	24.3	1,159,400	17.70
Sugarbeets	2007	Minnesota	Polk	100,800	99,800	25.6	2,553,400	16.20
Sugarbeets	2007	Minnesota	D10 Combined Counties	1,700	1,600	25.4	40,600	17.90
Sugarbeets	2007	Minnesota	D10 Northwest	302,500	299,000	23.6	7,051,500	16.00
Sugarbeets	2007	Minnesota	Chippewa	30,600	30,600	25.9	794,700	16.20
Sugarbeets	2007	Minnesota	Grant	10,300	10,200	19.8	202,300	16.90
Sugarbeets	2007	Minnesota	Otter Tail	2,300	2,300	18.9	43,500	17.20
Sugarbeets	2007	Minnesota	Pope	2,600	2,600	26.3	68,300	16.40
Sugarbeets	2007	Minnesota	Stevens	5,100	5,100	27.2	138,500	16.50
Sugarbeets	2007	Minnesota	Swift	6,200	6,100	25.5	155,300	16.50
Sugarbeets	2007	Minnesota	Traverse	6,500	6,400	20.8	132,900	17.20
Sugarbeets	2007	Minnesota	Wilkin	50,600	49,500	20.1	994,900	17.80
Sugarbeets	2007	Minnesota	Yellow Medicine	4,000	4,000	27.6	110,400	16.20
Sugarbeets	2007	Minnesota	D40 Combined Counties	800	800	25.4	21,100	17.00
Sugarbeets	2007	Minnesota	D40 West Central	119,100	117,700	22.6	2,662,200	17.00
Sugarbeets	2007	Minnesota	Kandiyohi	14,400	14,400	26.3	378,000	16.30
Sugarbeets	2007	Minnesota	McLeod	2,300	2,300	27.0	62,000	16.00
Sugarbeets	2007	Minnesota	Renville	35,400	35,300	27.4	966,600	15.90
Sugarbeets	2007	Minnesota	Sibley	2,100	2,100	29.0	60,900	15.60
Sugarbeets	2007	Minnesota	Stearns	2,600	2,600	24.1	62,300	16.20
Sugarbeets	2007	Minnesota	D50 Combined Counties	2,000	2,000	27.4	54,700	16.00
Sugarbeets	2007	Minnesota	D60 Central	56,700	56,600	27.0	1,532,700	16.00
Sugarbeets	2007	Minnesota	Redwood	4,600	4,600	27.1	124,500	15.70
Sugarbeets	2007	Minnesota	D70 Combined Counties	600	600	20.0	10,000	16.20
Sugarbeets	2007	Minnesota	D70 Southwest	5,100	5,100	26.4	134,500	15.80
Sugarbeets	2007	Minnesota	D98 Combined Districts	800	600	25.0	16,800	16.00
Sugarbeets	**2007**	**Minnesota**	**State Total**	**486,000**	**481,000**	**23.8**	**11,448,000**	**17.50**
Sugarbeets	2007	Montana	Dawson	2,360	2,360	22.7	53,500	17.84
Sugarbeets	2007	Montana	Richland	13,900	13,840	24.0	331,500	16.10
Sugarbeets	2007	Montana	D30 Combined Counties	1,930	1,930	22.2	42,800	17.84
Sugarbeets	2007	Montana	D30 Northeast	18,190	18,190	23.6	427,600	16.05
Sugarbeets	2007	Montana	Big Horn	9,670	9,670	26.6	257,000	15.46
Sugarbeets	2007	Montana	Carbon	3,680	3,630	25.6	93,400	16.31
Sugarbeets	2007	Montana	Treasure	3,320	3,330	27.8	92,200	15.37
Sugarbeets	2007	Montana	Yellowstone	7,640	7,490	22.9	172,000	15.64
Sugarbeets	2007	Montana	D80 Combined Counties	180	180	31.7	5,700	16.00
Sugarbeets	2007	Montana	D80 South Central	24,390	24,150	25.8	618,500	15.71
Sugarbeets	2007	Montana	Custer	650	650	25.8	16,600	17.21
Sugarbeets	2007	Montana	Prairie	1,790	1,720	23.6	42,000	16.07
Sugarbeets	2007	Montana	D90 Combined Counties	2,490	2,310	25.7	59,300	15.53
Sugarbeets	2007	Montana	D90 Southeast	4,820	4,740	24.9	117,900	16.68
Sugarbeets	**2007**	**Montana**	**State Total**	**47,500**	**47,000**	**24.7**	**1,161,000**	**16.67**
Sugarbeets	2007	Nebraska	Box Butte	20,100	19,900	23.8	474,300	17.16
Sugarbeets	2007	Nebraska	Cheyenne	1,800	1,800	23.9	43,100	16.60
Sugarbeets	2007	Nebraska	Deuel	600	600	19.3	11,600	15.09
Sugarbeets	2007	Nebraska	Kimball	3,300	3,100	25.3	78,500	16.67
Sugarbeets	2007	Nebraska	Morrill	5,200	4,900	22.8	111,700	15.63
Sugarbeets	2007	Nebraska	Scotts Bluff	7,100	6,800	23.1	156,300	15.68
Sugarbeets	2007	Nebraska	Sheridan	2,900	2,400	23.0	55,200	16.84
Sugarbeets	2007	Nebraska	Sioux	600	500	26.2	13,100	15.79
Sugarbeets	2007	Nebraska	D10 Combined Counties	500	500	21.4	10,700	17.31
Sugarbeets	2007	Nebraska	D10 Northwest	42,000	40,200	23.6	948,500	16.61
Sugarbeets	2007	Nebraska	Chase	2,700	2,500	22.2	55,400	15.51
Sugarbeets	2007	Nebraska	Keith	2,000	1,300	23.2	30,200	16.08
Sugarbeets	2007	Nebraska	Perkins	800	300	23.0	6,900	15.17
Sugarbeets	2007	Nebraska	D70 Southwest	5,500	4,100	22.6	92,500	15.67
Sugarbeets	**2007**	**Nebraska**	**State Total**	**47,500**	**44,300**	**23.5**	**1,041,000**	**16.52**
Sugarbeets	2007	North Dakota	Williams	4,100	4,000	21.0	84,000	15.97
Sugarbeets	2007	North Dakota	D10 Northwest	4,100	4,000	21.0	84,000	15.97
Sugarbeets	2007	North Dakota	Grand Forks	30,900	30,600	25.5	780,000	17.95
Sugarbeets	2007	North Dakota	Pembina	79,100	78,200	22.9	1,791,000	16.25
Sugarbeets	2007	North Dakota	Walsh	44,000	43,100	23.5	1,014,000	15.19
Sugarbeets	2007	North Dakota	D30 Northeast	154,000	151,900	23.6	3,585,000	16.17
Sugarbeets	2007	North Dakota	McKenzie	10,500	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	D40 West Central	10,600	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	Cass	24,600	23,800	22.8	535,000	17.48
Sugarbeets	2007	North Dakota	Steele	300	300	26.7	8,000	15.53
Sugarbeets	2007	North Dakota	Traill	27,400	26,600	24.1	641,000	17.66
Sugarbeets	2007	North Dakota	D60 East Central	52,300	50,700	23.4	1,184,000	17.56

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	Minnesota	Clay	52,200	51,200	21.6	1,106,400	17.10
Sugarbeets	2007	Minnesota	Kittson	35,900	36,600	20.4	747,400	16.60
Sugarbeets	2007	Minnesota	Mahnomen	5,600	5,600	23.6	131,600	17.60
Sugarbeets	2007	Minnesota	Marshall	46,300	45,700	22.9	1,045,000	16.90
Sugarbeets	2007	Minnesota	Norman	45,300	47,700	24.3	1,159,400	17.70
Sugarbeets	2007	Minnesota	Polk	100,600	99,800	25.6	2,553,400	16.20
Sugarbeets	2007	Minnesota	D10 Combined Counties	1,700	1,600	25.4	40,600	17.90
Sugarbeets	2007	Minnesota	D10 Northwest	302,500	299,000	23.6	7,051,500	16.90
Sugarbeets	2007	Minnesota	Chippewa	30,600	30,600	26.0	794,700	16.20
Sugarbeets	2007	Minnesota	Grant	10,300	10,200	19.8	202,300	16.90
Sugarbeets	2007	Minnesota	Otter Tail	2,300	2,300	18.9	43,500	17.20
Sugarbeets	2007	Minnesota	Pope	2,600	2,600	26.3	68,300	16.40
Sugarbeets	2007	Minnesota	Stevens	5,100	5,100	27.2	138,500	16.50
Sugarbeets	2007	Minnesota	Swift	6,200	6,100	25.5	155,300	16.80
Sugarbeets	2007	Minnesota	Traverse	6,500	6,400	20.2	132,900	17.20
Sugarbeets	2007	Minnesota	Wilkin	50,600	49,500	20.1	994,900	17.60
Sugarbeets	2007	Minnesota	Yellow Medicine	4,000	4,000	27.6	110,400	16.20
Sugarbeets	2007	Minnesota	D40 Combined Counties	900	900	23.4	21,100	17.00
Sugarbeets	2007	Minnesota	D40 West Central	119,100	117,700	22.6	2,662,200	17.00
Sugarbeets	2007	Minnesota	Kandiyohi	14,400	14,400	26.3	378,000	16.30
Sugarbeets	2007	Minnesota	McLeod	2,300	2,300	27.0	62,000	16.00
Sugarbeets	2007	Minnesota	Renville	35,400	35,300	27.4	966,600	15.90
Sugarbeets	2007	Minnesota	Sibley	2,100	2,100	29.0	60,900	15.80
Sugarbeets	2007	Minnesota	Stearns	2,500	2,500	24.1	60,300	16.20
Sugarbeets	2007	Minnesota	D50 Combined Counties	2,000	2,000	27.4	54,700	16.00
Sugarbeets	2007	Minnesota	D60 Central	55,700	56,600	27.0	1,532,700	16.00
Sugarbeets	2007	Minnesota	Redwood	4,600	4,600	27.1	124,500	15.70
Sugarbeets	2007	Minnesota	D70 Combined Counties	500	500	20.0	10,000	16.20
Sugarbeets	2007	Minnesota	D70 Southwest	5,100	5,100	26.4	134,500	15.80
Sugarbeets	2007	Minnesota	D98 Combined Districts	600	600	25.0	15,800	16.00
Sugarbeets	**2007**	**Minnesota**	**State Total**	**485,000**	**481,000**	**23.8**	**11,448,000**	**17.50**
Sugarbeets	2007	Montana	Dawson	2,360	2,360	22.7	53,600	17.64
Sugarbeets	2007	Montana	Richland	13,900	13,840	24.0	331,500	15.10
Sugarbeets	2007	Montana	D30 Combined Counties	1,930	1,930	22.2	42,800	17.94
Sugarbeets	2007	Montana	D30 Northeast	18,190	18,130	23.6	427,600	16.05
Sugarbeets	2007	Montana	Big Horn	9,670	9,670	26.6	257,000	15.46
Sugarbeets	2007	Montana	Carbon	3,560	3,530	25.6	90,400	15.31
Sugarbeets	2007	Montana	Treasure	3,320	3,320	27.8	92,200	15.37
Sugarbeets	2007	Montana	Yellowstone	7,440	7,430	23.9	178,000	15.84
Sugarbeets	2007	Montana	D80 Combined Counties	180	180	31.7	5,700	16.00
Sugarbeets	2007	Montana	D80 South Central	24,360	24,130	25.5	615,300	15.71
Sugarbeets	2007	Montana	Custer	650	630	25.5	16,600	17.21
Sugarbeets	2007	Montana	Prairie	1,780	1,780	23.6	42,000	16.07
Sugarbeets	2007	Montana	D90 Combined Counties	2,490	2,310	25.7	59,300	15.53
Sugarbeets	2007	Montana	D90 Southeast	4,930	4,740	24.9	117,900	16.66
Sugarbeets	**2007**	**Montana**	**State Total**	**47,500**	**47,000**	**24.7**	**1,161,000**	**16.67**
Sugarbeets	2007	Nebraska	Box Butte	20,100	19,900	23.8	474,300	17.16
Sugarbeets	2007	Nebraska	Cheyenne	1,800	1,800	23.9	43,100	16.80
Sugarbeets	2007	Nebraska	Deuel	600	600	19.3	11,600	16.09
Sugarbeets	2007	Nebraska	Kimball	3,300	3,100	25.3	78,500	16.67
Sugarbeets	2007	Nebraska	Morrill	5,200	4,900	22.8	111,700	15.63
Sugarbeets	2007	Nebraska	Scotts Bluff	7,100	6,500	23.1	150,300	15.58
Sugarbeets	2007	Nebraska	Sheridan	2,900	2,400	23.0	55,200	16.64
Sugarbeets	2007	Nebraska	Sioux	500	500	26.2	13,100	15.79
Sugarbeets	2007	Nebraska	D10 Combined Counties	500	500	21.4	10,700	17.31
Sugarbeets	2007	Nebraska	D10 Northwest	42,000	40,200	23.6	948,500	16.61
Sugarbeets	2007	Nebraska	Chase	2,700	2,600	22.2	55,400	15.51
Sugarbeets	2007	Nebraska	Keith	2,000	1,300	23.3	30,200	16.08
Sugarbeets	2007	Nebraska	Perkins	800	300	23.0	6,900	15.17
Sugarbeets	2007	Nebraska	D70 Southwest	5,500	4,100	22.6	92,500	15.67
Sugarbeets	**2007**	**Nebraska**	**State Total**	**47,500**	**44,300**	**23.5**	**1,041,000**	**16.52**
Sugarbeets	2007	North Dakota	Williams	4,100	4,000	21.0	84,000	16.97
Sugarbeets	2007	North Dakota	D10 Northwest	4,100	4,000	21.0	84,000	16.97
Sugarbeets	2007	North Dakota	Grand Forks	30,900	30,600	25.5	780,000	17.05
Sugarbeets	2007	North Dakota	Pembina	79,100	78,200	22.9	1,791,000	15.25
Sugarbeets	2007	North Dakota	Walsh	44,000	43,100	23.5	1,014,000	15.19
Sugarbeets	2007	North Dakota	D30 Northeast	154,000	151,900	25.6	3,885,000	15.17
Sugarbeets	2007	North Dakota	McKenzie	10,500	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	D40 West Central	10,500	10,400	24.7	257,000	15.69
Sugarbeets	2007	North Dakota	Cass	24,600	23,800	22.5	535,000	17.46
Sugarbeets	2007	North Dakota	Steele	300	300	26.7	8,000	15.53
Sugarbeets	2007	North Dakota	Traill	27,400	26,600	24.1	641,000	17.66
Sugarbeets	2007	North Dakota	D60 East Central	52,300	50,700	23.4	1,184,000	17.56

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	North Dakota	Richland	30,400	29,400	19.7	580,000	17.06
Sugarbeets	2007	North Dakota	D90 Combined Counties	700	600	25.7	16,000	16.71
Sugarbeets	2007	North Dakota	D90 Southeast	31,100	30,000	19.9	595,000	17.07
Sugarbeets	**2007**	**North Dakota**	**State Total**	**252,000**	**247,000**	**23.1**	**5,706,000**	**17.96**
Sugarbeets	2007	Oregon	Union	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	D30 Northeast	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	Malheur	9,900	9,000	33.3	300,000	15.69
Sugarbeets	2007	Oregon	D80 Southeast	9,900	9,000	33.3	300,000	15.69
Sugarbeets	**2007**	**Oregon**	**State Total**	**12,000**	**11,000**	**31.9**	**351,000**	**16.65**
Sugarbeets	2007	Washington	Benton	2,000	2,000	42.0	84,000	16.38
Sugarbeets	2007	Washington	D20 Central	2,000	2,000	42.0	84,000	16.38
Sugarbeets	**2007**	**Washington**	**State Total**	**2,000**	**2,000**	**42.0**	**84,000**	**16.38**
Sugarbeets	2007	Wyoming	Big Horn	6,700	6,600	18.9	123,000	16.88
Sugarbeets	2007	Wyoming	Fremont	1,400	1,400	24.3	34,000	17.21
Sugarbeets	2007	Wyoming	Park	11,800	11,600	21.9	254,000	16.87
Sugarbeets	2007	Wyoming	Washakie	6,700	6,600	24.1	159,000	16.83
Sugarbeets	2007	Wyoming	D10 Northwest	26,600	26,100	21.8	570,000	16.83
Sugarbeets	2007	Wyoming	Goshen	1,200	1,200	23.5	28,200	16.14
Sugarbeets	2007	Wyoming	Laramie	900	800	21.1	16,900	16.34
Sugarbeets	2007	Wyoming	Platte	2,100	2,100	20.4	42,900	17.21
Sugarbeets	2007	Wyoming	D50 Southeast	4,200	4,100	21.5	88,000	16.70
Sugarbeets	**2007**	**Wyoming**	**State Total**	**30,800**	**30,200**	**21.8**	**658,000**	**16.81**
Sugarbeets	2006	California	Fresno	11,100	11,000	31.0	341,000	15.06
Sugarbeets	2006	California	Kern	3,900	3,900	34.4	134,000	14.75
Sugarbeets	2006	California	Kings	1,700	1,700	29.4	50,000	13.98
Sugarbeets	2006	California	Merced	2,400	2,400	29.2	70,000	15.00
Sugarbeets	2006	California	D51 Combined Counties	500	500	30.0	15,000	15.05
Sugarbeets	2006	California	D51 San Joaquin Valley	19,800	19,500	31.3	610,000	15.26
Sugarbeets	2006	California	Imperial	23,700	23,600	40.1	946,000	16.50
Sugarbeets	2006	California	D80 Southern California	23,700	23,600	40.1	946,000	16.50
Sugarbeets	**2006**	**California**	**State Total**	**43,300**	**43,100**	**36.1**	**1,556,000**	**16.01**
Sugarbeets	2006	Colorado	Boulder	1,000	700	11.1	7,800	16.45
Sugarbeets	2006	Colorado	Larimer	3,300	2,700	17.4	47,000	17.33
Sugarbeets	2006	Colorado	Logan	4,900	4,500	20.8	93,400	15.53
Sugarbeets	2006	Colorado	Morgan	2,300	2,300	25.9	59,600	15.86
Sugarbeets	2006	Colorado	Sedgwick	2,000	1,900	22.3	42,300	16.66
Sugarbeets	2006	Colorado	Weld	15,100	12,700	21.0	267,000	16.30
Sugarbeets	2006	Colorado	D20 Northeast	28,600	24,800	20.8	517,000	16.25
Sugarbeets	2006	Colorado	Adams	600	500	24.0	12,000	16.49
Sugarbeets	2006	Colorado	Kit Carson	800	600	28.7	17,200	16.31
Sugarbeets	2006	Colorado	Phillips	4,100	4,000	27.7	110,500	15.70
Sugarbeets	2006	Colorado	Washington	1,600	1,500	22.8	34,200	15.57
Sugarbeets	2006	Colorado	Yuma	6,600	6,600	30.0	197,500	16.09
Sugarbeets	2006	Colorado	D60 East Central	13,500	13,200	28.2	372,000	15.95
Sugarbeets	**2006**	**Colorado**	**State Total**	**42,100**	**38,000**	**23.4**	**889,000**	**16.09**
Sugarbeets	2006	Idaho	Ada	2,800	2,800	35.0	98,000	17.66
Sugarbeets	2006	Idaho	Canyon	11,400	11,300	34.6	391,000	16.45
Sugarbeets	2006	Idaho	Elmore	10,600	10,500	31.2	328,000	16.98
Sugarbeets	2006	Idaho	Owyhee	4,800	4,700	30.4	143,000	16.77
Sugarbeets	2006	Idaho	Washington	1,800	1,800	27.2	49,000	16.42
Sugarbeets	2006	Idaho	D70 Combined Counties	1,500	1,400	29.3	41,000	16.64
Sugarbeets	2006	Idaho	D70 Southwest	33,000	32,500	32.3	1,050,000	16.79
Sugarbeets	2006	Idaho	Cassia	33,600	33,600	30.5	1,025,000	17.43
Sugarbeets	2006	Idaho	Jerome	15,100	15,000	30.5	456,000	17.43
Sugarbeets	2006	Idaho	Lincoln	5,900	5,900	28.1	166,000	17.62
Sugarbeets	2006	Idaho	Minidoka	47,500	47,400	31.2	1,484,000	17.31
Sugarbeets	2006	Idaho	Twin Falls	12,800	12,700	32.5	413,000	17.02
Sugarbeets	2006	Idaho	D80 Combined Counties	2,900	2,900	33.4	97,000	16.68
Sugarbeets	2006	Idaho	D80 South Central	118,000	117,500	31.0	3,643,000	17.33
Sugarbeets	2006	Idaho	Bingham	23,200	23,200	33.9	786,000	17.22
Sugarbeets	2006	Idaho	Power	13,800	13,800	32.5	449,000	17.15
Sugarbeets	2006	Idaho	D90 East	37,000	37,000	33.4	1,235,000	17.19
Sugarbeets	**2006**	**Idaho**	**State Total**	**188,000**	**187,000**	**31.7**	**5,928,000**	**17.11**
Sugarbeets	2006	Michigan	D30 Combined Counties	600	600	15.0	9,000	17.50
Sugarbeets	2006	Michigan	D30 Northeast	500	500	18.0	9,000	17.50
Sugarbeets	2006	Michigan	Gladwin	1,000	1,000	19.0	19,000	15.50
Sugarbeets	2006	Michigan	Gratiot	11,600	11,200	18.2	310,000	17.80
Sugarbeets	2006	Michigan	Midland	4,000	3,900	19.2	75,000	15.10
Sugarbeets	2006	Michigan	D50 Combined Counties	900	900	17.8	15,000	17.20
Sugarbeets	2006	Michigan	D50 Central	17,500	17,000	15.8	320,000	17.90
Sugarbeets	2006	Michigan	Arenac	3,600	3,500	21.1	74,000	16.30
Sugarbeets	2006	Michigan	Bay	14,700	14,600	20.3	296,000	15.10
Sugarbeets	2006	Michigan	Huron	55,500	55,400	24.9	1,380,000	15.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	North Dakota	Richland	30,400	29,400	19.7	580,000	17.08
Sugarbeets	2007	North Dakota	D90 Combined Counties	700	600	26.7	16,000	16.71
Sugarbeets	2007	North Dakota	D90 Southeast	31,100	30,000	19.9	595,000	17.07
Sugarbeets	**2007**	**North Dakota**	**State Total**	**252,000**	**247,000**	**23.1**	**5,706,000**	**17.96**
Sugarbeets	2007	Oregon	Union	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	D30 Northeast	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	Malheur	9,900	9,000	33.3	300,000	15.69
Sugarbeets	2007	Oregon	D80 Southeast	9,900	9,000	33.3	300,000	15.69
Sugarbeets	**2007**	**Oregon**	**State Total**	**12,000**	**11,000**	**31.9**	**351,000**	**16.65**
Sugarbeets	2007	Washington	Benton	2,000	2,000	42.0	84,000	16.38
Sugarbeets	2007	Washington	D20 Central	2,000	2,000	42.0	84,000	16.38
Sugarbeets	**2007**	**Washington**	**State Total**	**2,000**	**2,000**	**42.0**	**84,000**	**16.38**
Sugarbeets	2007	Wyoming	Big Horn	6,700	6,500	18.9	123,000	16.88
Sugarbeets	2007	Wyoming	Fremont	1,400	1,400	24.3	34,000	17.21
Sugarbeets	2007	Wyoming	Park	11,800	11,600	21.9	254,000	16.87
Sugarbeets	2007	Wyoming	Washakie	6,700	6,600	24.1	159,000	16.83
Sugarbeets	2007	Wyoming	D10 Northwest	26,600	26,100	21.8	570,000	16.83
Sugarbeets	2007	Wyoming	Goshen	1,200	1,200	23.5	28,200	16.14
Sugarbeets	2007	Wyoming	Laramie	900	800	21.1	16,900	16.34
Sugarbeets	2007	Wyoming	Platte	2,100	2,100	20.4	42,900	17.21
Sugarbeets	2007	Wyoming	D50 Southeast	4,200	4,100	21.5	88,000	16.70
Sugarbeets	**2007**	**Wyoming**	**State Total**	**30,800**	**30,200**	**21.8**	**658,000**	**16.81**
Sugarbeets	2006	California	Fresno	11,100	11,000	31.0	341,000	15.06
Sugarbeets	2006	California	Kern	3,900	3,900	34.4	134,000	14.75
Sugarbeets	2006	California	Kings	1,700	1,700	29.4	50,000	13.98
Sugarbeets	2006	California	Merced	2,400	2,400	29.2	70,000	15.00
Sugarbeets	2006	California	D51 Combined Counties	500	500	30.0	15,000	15.05
Sugarbeets	2006	California	D51 San Joaquin Valley	19,600	19,500	31.3	610,000	15.26
Sugarbeets	2006	California	Imperial	23,700	23,600	40.1	945,000	16.50
Sugarbeets	2006	California	D80 Southern California	23,700	23,600	40.1	945,000	16.50
Sugarbeets	**2006**	**California**	**State Total**	**43,300**	**43,100**	**36.1**	**1,556,000**	**16.01**
Sugarbeets	2006	Colorado	Boulder	1,000	700	11.1	7,800	16.45
Sugarbeets	2006	Colorado	Larimer	3,300	2,700	17.4	47,000	17.33
Sugarbeets	2006	Colorado	Logan	4,900	4,500	20.2	93,450	15.55
Sugarbeets	2006	Colorado	Morgan	2,300	2,300	25.6	59,500	15.66
Sugarbeets	2006	Colorado	Sedgwick	2,000	1,900	22.3	42,300	16.66
Sugarbeets	2006	Colorado	Weld	15,100	12,700	21.0	267,000	16.30
Sugarbeets	2006	Colorado	D20 Northeast	25,600	24,800	20.8	517,000	16.25
Sugarbeets	2006	Colorado	Adams	600	500	24.0	12,000	16.49
Sugarbeets	2006	Colorado	Kit Carson	600	600	28.7	17,200	16.31
Sugarbeets	2006	Colorado	Phillips	4,100	4,000	27.7	110,600	15.70
Sugarbeets	2006	Colorado	Washington	1,600	1,500	22.8	34,200	15.57
Sugarbeets	2006	Colorado	Yuma	6,600	6,600	30.0	197,500	16.09
Sugarbeets	2006	Colorado	D60 East Central	13,600	13,200	28.2	372,000	15.96
Sugarbeets	**2006**	**Colorado**	**State Total**	**42,100**	**38,000**	**23.4**	**889,000**	**16.09**
Sugarbeets	2006	Idaho	Ada	2,800	2,800	35.0	98,000	17.66
Sugarbeets	2006	Idaho	Canyon	11,400	11,300	34.6	391,000	16.45
Sugarbeets	2006	Idaho	Elmore	10,600	10,500	31.2	328,000	16.96
Sugarbeets	2006	Idaho	Owyhee	4,800	4,700	30.4	143,000	16.77
Sugarbeets	2006	Idaho	Washington	1,900	1,800	27.2	49,000	16.42
Sugarbeets	2006	Idaho	D70 Combined Counties	1,500	1,400	29.3	41,000	16.64
Sugarbeets	2006	Idaho	D70 Southwest	33,000	32,500	32.3	1,050,000	16.70
Sugarbeets	2006	Idaho	Cassia	33,800	33,600	30.5	1,025,000	17.42
Sugarbeets	2006	Idaho	Jerome	15,100	15,000	30.5	459,000	17.43
Sugarbeets	2006	Idaho	Lincoln	5,900	5,900	28.1	165,000	17.62
Sugarbeets	2006	Idaho	Minidoka	47,500	47,400	31.3	1,484,000	17.31
Sugarbeets	2006	Idaho	Twin Falls	12,800	12,700	32.6	413,000	17.02
Sugarbeets	2006	Idaho	D80 Combined Counties	2,900	2,900	33.4	97,000	16.88
Sugarbeets	2006	Idaho	D80 South Central	118,000	117,500	31.0	3,643,000	17.33
Sugarbeets	2006	Idaho	Bingham	23,200	23,200	33.9	786,000	17.22
Sugarbeets	2006	Idaho	Power	13,800	13,800	32.5	449,000	17.15
Sugarbeets	2006	Idaho	D90 East	37,000	37,000	33.4	1,235,000	17.19
Sugarbeets	**2006**	**Idaho**	**State Total**	**188,000**	**187,000**	**31.7**	**5,928,000**	**17.11**
Sugarbeets	2006	Michigan	D30 Combined Counties	600	600	15.0	9,000	17.50
Sugarbeets	2006	Michigan	D30 Northeast	600	500	18.0	9,000	17.50
Sugarbeets	2006	Michigan	Gladwin	1,000	1,000	19.0	19,000	16.50
Sugarbeets	2006	Michigan	Gratiot	11,600	11,200	18.8	210,000	17.80
Sugarbeets	2006	Michigan	Midland	4,000	3,900	19.2	75,000	15.10
Sugarbeets	2006	Michigan	D50 Combined Counties	900	900	17.2	15,000	17.20
Sugarbeets	2006	Michigan	D50 Central	17,500	17,000	15.8	320,000	17.90
Sugarbeets	2006	Michigan	Arenac	3,500	3,500	21.1	74,000	15.30
Sugarbeets	2006	Michigan	Bay	14,700	14,600	20.3	295,000	15.10
Sugarbeets	2006	Michigan	Huron	55,500	55,400	24.9	1,380,000	15.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	North Dakota	Richland	30,400	29,400	19.7	580,000	17.09
Sugarbeets	2007	North Dakota	D90 Combined Counties	700	600	26.7	16,000	16.71
Sugarbeets	2007	North Dakota	D90 Southeast	31,100	30,000	19.9	595,000	17.07
Sugarbeets	**2007**	**North Dakota**	**State Total**	**252,000**	**247,000**	**23.1**	**5,706,000**	**17.96**
Sugarbeets	2007	Oregon	Union	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	D30 Northeast	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	Malheur	9,900	9,000	33.3	300,000	15.89
Sugarbeets	2007	Oregon	D80 Southeast	9,900	9,000	33.3	300,000	15.89
Sugarbeets	**2007**	**Oregon**	**State Total**	**12,000**	**11,000**	**31.9**	**351,000**	**16.65**
Sugarbeets	2007	Washington	Benton	2,000	2,000	42.0	84,000	16.38
Sugarbeets	2007	Washington	D20 Central	2,000	2,000	42.0	84,000	16.38
Sugarbeets	**2007**	**Washington**	**State Total**	**2,000**	**2,000**	**42.0**	**84,000**	**16.38**
Sugarbeets	2007	Wyoming	Big Horn	6,700	6,600	18.9	123,000	15.89
Sugarbeets	2007	Wyoming	Fremont	1,400	1,400	24.3	34,000	17.21
Sugarbeets	2007	Wyoming	Park	11,800	11,600	21.9	254,000	16.87
Sugarbeets	2007	Wyoming	Washakie	6,700	6,600	24.1	159,000	16.83
Sugarbeets	2007	Wyoming	D10 Northwest	26,600	26,100	21.8	570,000	16.83
Sugarbeets	2007	Wyoming	Goshen	1,200	1,200	23.5	28,200	16.14
Sugarbeets	2007	Wyoming	Laramie	900	800	21.1	16,900	16.34
Sugarbeets	2007	Wyoming	Platte	2,100	2,100	20.4	42,800	17.21
Sugarbeets	2007	Wyoming	D50 Southeast	4,200	4,100	21.5	88,000	16.70
Sugarbeets	**2007**	**Wyoming**	**State Total**	**30,800**	**30,200**	**21.8**	**658,000**	**16.81**
Sugarbeets	2006	California	Fresno	11,100	11,000	31.0	341,000	15.06
Sugarbeets	2006	California	Kern	3,900	3,900	34.4	134,000	14.75
Sugarbeets	2006	California	Kings	1,700	1,700	29.4	50,000	13.98
Sugarbeets	2006	California	Merced	2,400	2,400	29.2	70,000	15.00
Sugarbeets	2006	California	D51 Combined Counties	500	500	30.0	15,000	15.05
Sugarbeets	2006	California	D51 San Joaquin Valley	19,600	19,500	31.3	610,000	15.26
Sugarbeets	2006	California	Imperial	23,700	23,600	40.1	946,000	16.50
Sugarbeets	2006	California	D80 Southern California	23,700	23,600	40.1	946,000	16.50
Sugarbeets	**2006**	**California**	**State Total**	**43,300**	**43,100**	**36.1**	**1,556,000**	**16.01**
Sugarbeets	2006	Colorado	Boulder	1,000	700	11.1	7,900	16.45
Sugarbeets	2006	Colorado	Larimer	3,300	2,700	17.4	47,000	17.33
Sugarbeets	2006	Colorado	Logan	4,900	4,500	20.8	93,400	15.53
Sugarbeets	2006	Colorado	Morgan	2,300	2,300	25.9	59,500	15.86
Sugarbeets	2006	Colorado	Sedgwick	2,000	1,900	22.3	42,300	16.86
Sugarbeets	2006	Colorado	Weld	15,100	12,700	21.0	267,000	16.30
Sugarbeets	2006	Colorado	D30 Northeast	28,600	24,800	20.8	517,000	16.25
Sugarbeets	2006	Colorado	Adams	600	500	24.0	12,000	16.49
Sugarbeets	2006	Colorado	Kit Carson	600	600	28.7	17,200	16.31
Sugarbeets	2006	Colorado	Phillips	4,100	4,000	27.7	110,500	15.70
Sugarbeets	2006	Colorado	Washington	1,600	1,500	22.8	34,200	15.57
Sugarbeets	2006	Colorado	Yuma	6,600	6,600	30.0	197,500	16.09
Sugarbeets	2006	Colorado	D60 East Central	13,500	13,200	28.2	372,000	15.95
Sugarbeets	**2006**	**Colorado**	**State Total**	**42,100**	**38,000**	**23.4**	**889,000**	**16.09**
Sugarbeets	2006	Idaho	Ada	2,800	2,800	35.0	98,000	17.65
Sugarbeets	2006	Idaho	Canyon	11,400	11,300	34.6	391,000	16.45
Sugarbeets	2006	Idaho	Elmore	10,600	10,500	31.2	328,000	16.08
Sugarbeets	2006	Idaho	Owyhee	4,800	4,700	30.4	143,000	16.77
Sugarbeets	2006	Idaho	Washington	1,900	1,800	27.2	49,000	16.42
Sugarbeets	2006	Idaho	D70 Combined Counties	1,500	1,400	29.3	41,000	16.64
Sugarbeets	2006	Idaho	D70 Southwest	33,000	32,500	32.3	1,050,000	16.76
Sugarbeets	2006	Idaho	Cassia	33,800	33,600	30.5	1,025,000	17.42
Sugarbeets	2006	Idaho	Jerome	15,100	15,000	30.5	458,000	17.43
Sugarbeets	2006	Idaho	Lincoln	6,900	6,900	28.1	195,000	17.62
Sugarbeets	2006	Idaho	Minidoka	47,500	47,400	31.3	1,484,000	17.31
Sugarbeets	2006	Idaho	Twin Falls	12,800	12,700	32.5	413,000	17.03
Sugarbeets	2006	Idaho	D80 Combined Counties	2,900	2,900	33.4	97,000	16.66
Sugarbeets	2006	Idaho	D80 South Central	118,000	117,500	31.0	3,643,000	17.33
Sugarbeets	2006	Idaho	Bingham	23,200	23,200	33.9	786,000	17.22
Sugarbeets	2006	Idaho	Power	13,800	13,800	32.5	449,000	17.15
Sugarbeets	2006	Idaho	D90 East	37,000	37,000	33.4	1,235,000	17.19
Sugarbeets	**2006**	**Idaho**	**State Total**	**188,000**	**187,000**	**31.7**	**5,928,000**	**17.11**
Sugarbeets	2006	Michigan	D30 Combined Counties	600	600	15.0	9,000	17.50
Sugarbeets	2006	Michigan	D30 Northeast	600	600	18.0	9,000	17.50
Sugarbeets	2006	Michigan	Gladwin	1,000	1,000	19.0	19,000	15.50
Sugarbeets	2006	Michigan	Gratiot	11,600	11,200	18.8	210,000	17.80
Sugarbeets	2006	Michigan	Midland	4,000	3,900	19.2	75,000	15.10
Sugarbeets	2006	Michigan	D60 Combined Counties	900	900	17.8	16,000	17.20
Sugarbeets	2006	Michigan	D60 Central	17,500	17,000	18.8	320,000	17.90
Sugarbeets	2006	Michigan	Arenac	3,500	3,500	21.1	74,000	15.30
Sugarbeets	2006	Michigan	Bay	14,700	14,600	20.3	295,000	15.10
Sugarbeets	2006	Michigan	Huron	55,500	55,400	24.9	1,380,000	15.30

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2007	North Dakota	Richland	30,400	28,400	19.7	560,000	17.06
Sugarbeets	2007	North Dakota	D90 Combined Counties	700	600	26.7	16,000	16.71
Sugarbeets	2007	North Dakota	D90 Southeast	31,100	30,000	19.9	595,000	17.07
Sugarbeets	**2007**	**North Dakota**	**State Total**	**252,000**	**247,000**	**23.1**	**5,706,000**	**17.96**
Sugarbeets	2007	Oregon	Union	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	D30 Northeast	2,100	2,000	25.5	51,000	16.91
Sugarbeets	2007	Oregon	Malheur	9,900	9,000	33.3	300,000	15.69
Sugarbeets	2007	Oregon	D80 Southeast	9,900	9,000	33.3	300,000	15.69
Sugarbeets	**2007**	**Oregon**	**State Total**	**12,000**	**11,000**	**31.9**	**351,000**	**16.65**
Sugarbeets	2007	Washington	Benton	2,000	2,000	42.0	84,000	16.38
Sugarbeets	2007	Washington	D20 Central	2,000	2,000	42.0	84,000	16.38
Sugarbeets	**2007**	**Washington**	**State Total**	**2,000**	**2,000**	**42.0**	**84,000**	**16.38**
Sugarbeets	2007	Wyoming	Big Horn	6,700	6,500	18.9	123,000	15.88
Sugarbeets	2007	Wyoming	Fremont	1,400	1,400	24.3	34,000	17.21
Sugarbeets	2007	Wyoming	Park	11,800	11,600	21.9	254,000	16.67
Sugarbeets	2007	Wyoming	Washakie	6,700	6,600	24.1	159,000	16.63
Sugarbeets	2007	Wyoming	D10 Northwest	26,600	26,100	21.8	570,000	16.63
Sugarbeets	2007	Wyoming	Goshen	1,200	1,200	23.5	28,200	16.14
Sugarbeets	2007	Wyoming	Laramie	900	800	21.1	16,900	16.34
Sugarbeets	2007	Wyoming	Platte	2,100	2,100	20.4	42,900	17.21
Sugarbeets	2007	Wyoming	D50 Southeast	4,200	4,100	21.5	88,000	16.70
Sugarbeets	**2007**	**Wyoming**	**State Total**	**30,800**	**30,200**	**21.8**	**658,000**	**16.81**
Sugarbeets	2006	California	Fresno	11,100	11,000	31.0	341,500	15.06
Sugarbeets	2006	California	Kern	3,900	3,800	34.4	134,000	14.75
Sugarbeets	2006	California	Kings	1,700	1,700	29.4	50,000	13.98
Sugarbeets	2006	California	Merced	2,400	2,400	29.2	70,000	15.00
Sugarbeets	2006	California	D51 Combined Counties	600	600	30.0	18,000	15.05
Sugarbeets	2006	California	D51 San Joaquin Valley	19,600	19,500	31.3	610,000	15.26
Sugarbeets	2006	California	Imperial	23,700	23,600	40.1	946,000	16.50
Sugarbeets	2006	California	D80 Southern California	23,700	23,600	40.1	946,000	16.50
Sugarbeets	**2006**	**California**	**State Total**	**43,300**	**43,100**	**36.1**	**1,556,000**	**16.01**
Sugarbeets	2006	Colorado	Boulder	1,000	700	11.1	7,800	15.45
Sugarbeets	2006	Colorado	Larimer	3,300	2,700	17.4	47,000	17.33
Sugarbeets	2006	Colorado	Logan	4,900	4,500	20.8	93,400	15.53
Sugarbeets	2006	Colorado	Morgan	2,300	2,300	25.9	59,500	15.68
Sugarbeets	2006	Colorado	Sedgwick	2,000	1,900	22.3	42,300	16.66
Sugarbeets	2006	Colorado	Weld	15,100	12,700	21.0	267,000	16.30
Sugarbeets	2006	Colorado	D20 Northeast	25,600	24,800	20.8	517,000	16.25
Sugarbeets	2006	Colorado	Adams	600	500	24.0	12,000	16.49
Sugarbeets	2006	Colorado	Kit Carson	600	600	28.7	17,200	16.31
Sugarbeets	2006	Colorado	Phillips	4,100	4,000	27.7	110,500	15.70
Sugarbeets	2006	Colorado	Washington	1,600	1,500	22.8	34,200	15.57
Sugarbeets	2006	Colorado	Yuma	6,600	6,600	30.0	197,500	16.09
Sugarbeets	2006	Colorado	D60 East Central	13,500	13,200	25.2	372,000	15.95
Sugarbeets	**2006**	**Colorado**	**State Total**	**42,100**	**38,000**	**23.4**	**889,000**	**16.09**
Sugarbeets	2006	Idaho	Ada	2,800	2,800	35.0	98,000	17.65
Sugarbeets	2006	Idaho	Canyon	11,400	11,300	34.6	391,000	18.45
Sugarbeets	2006	Idaho	Elmore	10,800	10,800	31.2	335,000	16.98
Sugarbeets	2006	Idaho	Owyhee	4,900	4,700	30.4	143,000	16.77
Sugarbeets	2006	Idaho	Washington	1,800	1,800	27.3	49,000	16.42
Sugarbeets	2006	Idaho	D70 Combined Counties	1,500	1,400	29.3	41,000	16.84
Sugarbeets	2006	Idaho	D70 Southwest	33,000	32,500	32.3	1,050,000	16.79
Sugarbeets	2006	Idaho	Cassia	33,800	33,600	30.5	1,025,000	17.42
Sugarbeets	2006	Idaho	Jerome	15,100	15,000	30.5	455,000	17.43
Sugarbeets	2006	Idaho	Lincoln	5,900	5,900	28.1	166,000	17.62
Sugarbeets	2006	Idaho	Minidoka	47,500	47,400	31.3	1,484,000	17.31
Sugarbeets	2006	Idaho	Twin Falls	12,800	13,700	32.5	413,000	17.02
Sugarbeets	2006	Idaho	D80 Combined Counties	2,900	2,900	33.4	97,000	16.68
Sugarbeets	2006	Idaho	D80 South Central	118,000	117,500	31.0	3,643,000	17.33
Sugarbeets	2006	Idaho	Bingham	23,200	23,200	33.9	785,000	17.22
Sugarbeets	2006	Idaho	Power	13,800	13,800	32.5	442,000	17.15
Sugarbeets	2006	Idaho	D90 East	37,000	37,000	33.4	1,235,000	17.19
Sugarbeets	**2006**	**Idaho**	**State Total**	**188,000**	**187,000**	**31.7**	**5,928,000**	**17.11**
Sugarbeets	2006	Michigan	D30 Combined Counties	500	500	18.0	9,000	17.50
Sugarbeets	2006	Michigan	D30 Northeast	500	500	18.0	9,000	17.50
Sugarbeets	2006	Michigan	Gladwin	1,000	1,000	19.0	19,000	18.20
Sugarbeets	2006	Michigan	Gratiot	11,600	11,200	18.8	210,000	17.60
Sugarbeets	2006	Michigan	Midland	4,000	3,900	19.2	75,000	15.10
Sugarbeets	2006	Michigan	D80 Combined Counties	900	900	17.8	16,000	17.20
Sugarbeets	2006	Michigan	D80 Central	17,500	17,000	15.8	320,000	17.90
Sugarbeets	2006	Michigan	Arenac	3,600	3,500	21.1	74,000	15.30
Sugarbeets	2006	Michigan	Bay	14,700	14,600	20.3	296,000	15.10
Sugarbeets	2006	Michigan	Huron	56,500	56,400	24.6	1,389,000	15.90

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Michigan	Saginaw	17,000	16,900	22.4	378,000	17.90
Sugarbeets	2006	Michigan	Sanilac	20,200	20,100	24.8	498,000	17.30
Sugarbeets	2006	Michigan	Tuscola	21,100	21,000	24.6	514,000	15.20
Sugarbeets	2006	Michigan	D80 East Central	132,000	131,500	23.9	3,140,000	15.10
Sugarbeets	2006	Michigan	Clinton	1,500	1,500	18.7	28,000	15.30
Sugarbeets	2006	Michigan	Ionia	500	500	22.0	11,000	21.10
Sugarbeets	2006	Michigan	Shiawassee	800	800	20.0	16,000	17.60
Sugarbeets	2006	Michigan	D80 South Central	2,600	2,800	19.6	55,000	18.70
Sugarbeets	2006	Michigan	Lapeer	900	900	24.4	22,000	17.30
Sugarbeets	2006	Michigan	D90 Combined Counties	1,300	1,300	20.8	27,000	17.20
Sugarbeets	2006	Michigan	D90 Southeast	2,200	2,200	22.3	49,000	17.20
Sugarbeets	**2006**	**Michigan**	**State Total**	**155,000**	**154,000**	**23.2**	**3,573,000**	**16.10**
Sugarbeets	2006	Minnesota	Becker	10,400	9,800	27.2	266,500	15.40
Sugarbeets	2006	Minnesota	Clay	56,400	52,700	29.9	1,567,100	15.10
Sugarbeets	2006	Minnesota	Kittson	35,500	33,100	23.8	625,300	19.00
Sugarbeets	2006	Minnesota	Mahnomen	5,100	4,400	24.1	105,900	15.20
Sugarbeets	2006	Minnesota	Marshall	45,700	41,500	22.9	949,500	15.50
Sugarbeets	2006	Minnesota	Norman	46,200	42,100	26.3	1,106,200	17.80
Sugarbeets	2006	Minnesota	Polk	102,400	93,300	24.8	2,314,500	15.00
Sugarbeets	2006	Minnesota	Red Lake	1,900	1,700	22.8	38,700	17.70
Sugarbeets	2006	Minnesota	D10 Combined Counties	400	400	22.3	8,900	17.90
Sugarbeets	2006	Minnesota	D10 Northwest	307,000	281,000	24.2	6,852,500	16.20
Sugarbeets	2006	Minnesota	Chippewa	32,200	32,200	23.2	747,300	16.50
Sugarbeets	2006	Minnesota	Grant	11,600	11,500	23.4	269,400	16.60
Sugarbeets	2006	Minnesota	Otter Tail	4,400	4,300	27.4	118,000	16.80
Sugarbeets	2006	Minnesota	Pope	3,800	3,800	24.8	94,400	16.60
Sugarbeets	2006	Minnesota	Stevens	4,100	4,100	25.5	104,700	17.00
Sugarbeets	2006	Minnesota	Swift	6,900	6,900	23.2	160,700	16.80
Sugarbeets	2006	Minnesota	Traverse	9,800	9,500	24.6	234,000	16.90
Sugarbeets	2006	Minnesota	Wilkin	50,900	50,400	26.7	1,343,400	17.20
Sugarbeets	2006	Minnesota	Yellow Medicine	3,800	3,600	23.2	85,700	16.70
Sugarbeets	2006	Minnesota	D40 Combined Counties	1,100	1,100	23.2	26,200	16.90
Sugarbeets	2006	Minnesota	D40 West Central	127,000	126,200	25.0	3,152,500	16.90
Sugarbeets	2006	Minnesota	Kandiyohi	16,400	16,300	25.6	416,500	16.80
Sugarbeets	2006	Minnesota	McLeod	2,700	2,700	22.6	61,000	16.90
Sugarbeets	2006	Minnesota	Meeker	2,300	2,300	25.5	58,600	16.80
Sugarbeets	2006	Minnesota	Renville	39,400	39,300	24.8	975,400	16.70
Sugarbeets	2006	Minnesota	Sibley	2,300	2,300	25.4	58,500	16.80
Sugarbeets	2006	Minnesota	Stearns	2,100	2,100	26.2	55,000	16.30
Sugarbeets	2006	Minnesota	D50 Central	66,200	66,000	25.0	1,625,100	16.70
Sugarbeets	2006	Minnesota	Redwood	3,800	3,200	28.3	55,500	16.50
Sugarbeets	2006	Minnesota	D70 Combined Counties	600	600	24.2	14,500	17.10
Sugarbeets	2006	Minnesota	D70 Southwest	4,400	4,400	23.4	103,000	16.60
Sugarbeets	2006	Minnesota	D95 Combined Districts	400	400	15.3	7,300	17.20
Sugarbeets	**2006**	**Minnesota**	**State Total**	**504,000**	**477,000**	**24.9**	**11,877,000**	**17.60**
Sugarbeets	2006	Montana	Dawson	2,930	2,220	20.9	59,000	17.26
Sugarbeets	2006	Montana	Richland	15,530	15,450	25.0	387,000	17.58
Sugarbeets	2006	Montana	Roosevelt	2,160	2,160	26.4	57,000	17.67
Sugarbeets	2006	Montana	D30 Northeast	20,640	20,430	24.6	502,000	17.55
Sugarbeets	2006	Montana	Big Horn	9,880	7,900	31.0	245,000	15.51
Sugarbeets	2006	Montana	Carbon	4,560	4,460	24.9	112,000	16.29
Sugarbeets	2006	Montana	Treasure	3,080	3,090	31.4	97,000	15.70
Sugarbeets	2006	Montana	Yellowstone	9,420	7,230	28.2	200,500	15.61
Sugarbeets	2006	Montana	D80 Combined Counties	320	280	32.9	9,200	16.32
Sugarbeets	2006	Montana	D80 South Central	27,860	23,590	29.0	683,700	15.71
Sugarbeets	2006	Montana	Custer	1,160	1,010	27.1	27,400	16.64
Sugarbeets	2006	Montana	Prairie	1,600	1,570	21.8	34,300	17.76
Sugarbeets	2006	Montana	Rosebud	2,340	1,900	32.4	61,600	15.93
Sugarbeets	2006	Montana	D90 Southeast	5,100	4,420	27.5	123,300	15.56
Sugarbeets	**2006**	**Montana**	**State Total**	**53,600**	**48,500**	**27.0**	**1,310,000**	**16.50**
Sugarbeets	2006	Nebraska	Banner	800	700	16.4	11,500	17.76
Sugarbeets	2006	Nebraska	Box Butte	23,000	22,700	23.0	521,700	17.51
Sugarbeets	2006	Nebraska	Cheyenne	2,900	2,900	24.4	70,900	17.96
Sugarbeets	2006	Nebraska	Deuel	900	800	23.8	19,000	16.66
Sugarbeets	2006	Nebraska	Kimball	4,800	4,300	21.2	91,300	17.70
Sugarbeets	2006	Nebraska	Morrill	5,400	5,100	23.3	118,700	16.16
Sugarbeets	2006	Nebraska	Scotts Bluff	11,500	10,100	23.0	231,500	16.22
Sugarbeets	2006	Nebraska	Sheridan	3,700	3,000	22.4	67,100	17.06
Sugarbeets	2006	Nebraska	D10 Combined Counties	1,000	900	26.1	23,500	16.97
Sugarbeets	2006	Nebraska	D10 Northwest	53,700	50,500	22.9	1,155,500	17.11
Sugarbeets	2006	Nebraska	Chase	3,800	3,200	28.4	108,100	15.40
Sugarbeets	2006	Nebraska	Keith	1,900	1,800	23.6	37,700	16.76
Sugarbeets	2006	Nebraska	Perkins	1,900	1,900	24.1	45,700	16.40

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Nebraska	D70 Southwest	7,600	7,300	26.2	191,500	15.91
Sugarbeets	**2006**	**Nebraska**	**State Total**	**61,300**	**57,800**	**23.3**	**1,347,000**	**16.94**
Sugarbeets	2006	North Dakota	Williams	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	D10 Northwest	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	Grand Forks	32,900	30,400	27.0	822,000	17.65
Sugarbeets	2006	North Dakota	Pembina	79,700	73,200	25.9	1,922,000	15.59
Sugarbeets	2006	North Dakota	Walsh	45,600	41,600	25.3	1,054,000	15.44
Sugarbeets	2006	North Dakota	D30 Northeast	158,200	145,200	26.0	3,769,000	16.34
Sugarbeets	2006	North Dakota	McKenzie	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	D40 West Central	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	Cass	28,700	24,700	26.4	651,000	17.94
Sugarbeets	2006	North Dakota	Traill	29,200	26,900	27.1	730,000	17.68
Sugarbeets	2006	North Dakota	D60 Combined Counties	200	100	30.0	3,000	17.24
Sugarbeets	2006	North Dakota	D50 East Central	58,100	51,700	26.8	1,384,000	17.75
Sugarbeets	2006	North Dakota	Ransom	100	100	30.0	3,000	16.83
Sugarbeets	2006	North Dakota	Richland	31,300	30,200	25.4	753,000	16.99
Sugarbeets	2006	North Dakota	D90 Southeast	31,400	30,900	25.4	795,000	16.99
Sugarbeets	**2006**	**North Dakota**	**State Total**	**261,000**	**243,000**	**26.0**	**6,318,000**	**16.01**
Sugarbeets	2006	Oregon	Union	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	D30 Northeast	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	Malheur	10,800	10,800	31.3	337,700	16.09
Sugarbeets	2006	Oregon	D20 Southeast	10,800	10,200	31.3	337,700	16.09
Sugarbeets	**2006**	**Oregon**	**State Total**	**13,100**	**13,100**	**30.1**	**394,000**	**17.15**
Sugarbeets	2006	Washington	Benton	2,000	2,000	37.0	74,000	16.40
Sugarbeets	2006	Washington	D20 Central	2,000	2,000	37.0	74,000	16.40
Sugarbeets	**2006**	**Washington**	**State Total**	**2,000**	**2,000**	**37.0**	**74,000**	**16.40**
Sugarbeets	2006	Wyoming	Big Horn	12,400	11,300	18.0	203,500	17.00
Sugarbeets	2006	Wyoming	Fremont	3,900	3,200	18.7	41,200	17.13
Sugarbeets	2006	Wyoming	Park	12,700	12,600	22.2	252,000	17.10
Sugarbeets	2006	Wyoming	Washakie	9,400	9,100	19.6	178,000	17.23
Sugarbeets	2006	Wyoming	D10 Northwest	37,400	35,200	20.0	703,000	17.10
Sugarbeets	2006	Wyoming	Goshen	1,600	1,400	21.9	30,600	17.35
Sugarbeets	2006	Wyoming	Laramie	1,000	900	20.7	18,600	17.48
Sugarbeets	2006	Wyoming	Platte	2,800	2,600	17.6	45,800	15.27
Sugarbeets	2006	Wyoming	D50 Southeast	5,400	4,900	19.4	95,000	17.81
Sugarbeets	**2006**	**Wyoming**	**State Total**	**42,800**	**40,100**	**19.9**	**798,000**	**17.18**
Sugarbeets	2005	California	Fresno	11,000	10,700	36.3	390,000	14.72
Sugarbeets	2005	California	Kern	4,700	4,700	40.4	190,000	14.07
Sugarbeets	2005	California	Kings	800	200	26.8	23,000	15.22
Sugarbeets	2005	California	Merced	3,600	3,600	31.1	112,000	15.43
Sugarbeets	2005	California	D51 Combined Counties	900	900	31.1	28,000	14.96
Sugarbeets	2005	California	D51 San Joaquin Valley	21,000	20,700	35.4	732,000	14.66
Sugarbeets	2005	California	Imperial	23,400	23,400	38.6	903,000	16.66
Sugarbeets	2005	California	D20 Southern California	23,400	23,400	38.6	903,000	16.66
Sugarbeets	**2005**	**California**	**State Total**	**44,400**	**44,100**	**37.1**	**1,636,000**	**15.79**
Sugarbeets	2005	Colorado	Boulder	700	600	25.3	15,200	16.83
Sugarbeets	2005	Colorado	Larimer	2,700	2,700	21.5	58,100	16.88
Sugarbeets	2005	Colorado	Logan	4,500	4,300	21.9	94,300	15.06
Sugarbeets	2005	Colorado	Morgan	2,400	2,200	26.0	57,100	15.43
Sugarbeets	2005	Colorado	Sedgwick	1,900	1,800	21.9	39,400	16.01
Sugarbeets	2005	Colorado	Weld	13,700	13,300	25.3	336,000	16.13
Sugarbeets	2005	Colorado	D20 Northeast	25,900	24,600	24.1	600,000	15.96
Sugarbeets	2005	Colorado	Adams	400	400	21.5	8,600	16.51
Sugarbeets	2005	Colorado	Kit Carson	500	500	23.8	11,900	15.34
Sugarbeets	2005	Colorado	Phillips	2,800	2,800	25.0	69,900	15.77
Sugarbeets	2005	Colorado	Washington	1,400	1,300	22.8	29,600	15.99
Sugarbeets	2005	Colorado	Yuma	5,400	4,400	25.7	113,000	15.45
Sugarbeets	2005	Colorado	D60 East Central	10,500	9,400	24.8	233,000	15.57
Sugarbeets	**2005**	**Colorado**	**State Total**	**36,400**	**34,300**	**24.3**	**833,000**	**15.87**
Sugarbeets	2005	Idaho	Ada	2,900	2,800	30.0	84,000	15.48
Sugarbeets	2005	Idaho	Canyon	10,100	9,900	29.9	296,000	16.45
Sugarbeets	2005	Idaho	Elmore	7,700	7,600	25.8	195,000	17.43
Sugarbeets	2005	Idaho	Owyhee	5,200	4,800	29.2	140,000	16.68
Sugarbeets	2005	Idaho	Payette	1,400	1,300	28.5	37,000	16.23
Sugarbeets	2005	Idaho	Washington	1,500	1,400	30.7	43,000	16.32
Sugarbeets	2005	Idaho	D70 Combined Counties	200	200	20.0	4,000	16.26
Sugarbeets	2005	Idaho	D70 Southwest	29,000	28,000	28.8	800,000	16.72
Sugarbeets	2005	Idaho	Cassia	30,800	30,500	26.8	817,000	17.84
Sugarbeets	2005	Idaho	Gooding	2,000	2,000	24.0	48,000	17.10
Sugarbeets	2005	Idaho	Jerome	14,000	13,900	25.2	350,000	17.90
Sugarbeets	2005	Idaho	Lincoln	8,000	7,800	24.9	197,000	17.86
Sugarbeets	2005	Idaho	Minidoka	42,500	42,400	26.0	1,104,000	17.82
Sugarbeets	2005	Idaho	Twin Falls	10,400	10,400	26.3	274,000	17.46

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Michigan	Saginaw	17,000	16,900	22.4	378,000	17.90
Sugarbeets	2006	Michigan	Sanilac	20,200	20,100	24.6	495,000	17.30
Sugarbeets	2006	Michigan	Tuscola	21,100	21,000	24.6	514,000	15.20
Sugarbeets	2006	Michigan	D60 East Central	132,000	131,600	23.9	3,140,000	15.10
Sugarbeets	2006	Michigan	Clinton	1,500	1,500	18.7	28,000	15.30
Sugarbeets	2006	Michigan	Ionia	500	500	22.0	11,000	21.10
Sugarbeets	2006	Michigan	Shiawassee	800	800	20.0	16,000	17.60
Sugarbeets	2006	Michigan	D80 South Central	2,800	2,800	19.6	55,000	15.70
Sugarbeets	2006	Michigan	Lapeer	900	900	24.4	22,000	17.30
Sugarbeets	2006	Michigan	D90 Combined Counties	1,300	1,300	20.8	27,000	17.20
Sugarbeets	2006	Michigan	D90 Southeast	2,200	2,200	22.3	49,000	17.20
Sugarbeets	**2006**	**Michigan**	**State Total**	**155,000**	**154,000**	**23.2**	**3,573,000**	**16.10**
Sugarbeets	2006	Minnesota	Becker	10,400	9,800	27.2	266,600	16.40
Sugarbeets	2006	Minnesota	Clay	56,400	52,700	25.9	1,367,100	15.10
Sugarbeets	2006	Minnesota	Kittson	36,600	36,100	23.5	525,300	19.00
Sugarbeets	2006	Minnesota	Mahnomen	5,100	4,400	24.1	105,900	16.20
Sugarbeets	2006	Minnesota	Marshall	45,700	41,500	22.9	949,300	15.50
Sugarbeets	2006	Minnesota	Norman	46,200	42,100	26.3	1,106,200	17.80
Sugarbeets	2006	Minnesota	Polk	102,400	93,300	24.8	2,314,500	15.00
Sugarbeets	2006	Minnesota	Red Lake	1,900	1,700	22.8	38,700	17.70
Sugarbeets	2006	Minnesota	D10 Combined Counties	400	400	22.3	9,000	17.90
Sugarbeets	2006	Minnesota	D10 Northwest	307,000	291,000	24.2	6,992,500	16.20
Sugarbeets	2006	Minnesota	Chippewa	32,200	32,200	23.2	747,300	16.50
Sugarbeets	2006	Minnesota	Grant	11,600	11,500	23.4	269,400	16.80
Sugarbeets	2006	Minnesota	Otter Tail	4,400	4,300	27.4	118,000	16.80
Sugarbeets	2006	Minnesota	Pope	3,800	3,800	24.8	92,400	16.90
Sugarbeets	2006	Minnesota	Stevens	4,100	4,100	25.5	104,700	17.00
Sugarbeets	2006	Minnesota	Swift	5,900	5,900	23.8	140,700	16.80
Sugarbeets	2006	Minnesota	Traverse	9,600	9,500	24.6	234,000	16.90
Sugarbeets	2006	Minnesota	Wilkin	50,900	50,400	26.7	1,349,400	17.20
Sugarbeets	2006	Minnesota	Yellow Medicine	3,800	3,800	23.8	90,700	16.70
Sugarbeets	2006	Minnesota	D40 Combined Counties	1,100	1,100	23.8	26,200	16.90
Sugarbeets	2006	Minnesota	D40 West Central	127,000	126,200	25.0	3,158,500	16.90
Sugarbeets	2006	Minnesota	Kandiyohi	16,400	16,300	25.6	416,600	16.60
Sugarbeets	2006	Minnesota	McLeod	2,700	2,700	22.6	61,000	16.90
Sugarbeets	2006	Minnesota	Meeker	2,300	2,300	26.5	60,800	16.60
Sugarbeets	2006	Minnesota	Renville	39,400	39,300	24.8	975,400	16.70
Sugarbeets	2006	Minnesota	Sibley	2,300	2,300	25.4	58,500	16.80
Sugarbeets	2006	Minnesota	Stearns	2,100	2,100	26.2	55,000	16.30
Sugarbeets	2006	Minnesota	D50 Central	65,200	65,000	25.0	1,625,100	16.70
Sugarbeets	2006	Minnesota	Redwood	3,600	3,600	23.3	83,600	16.60
Sugarbeets	2006	Minnesota	D70 Combined Counties	600	600	24.2	14,500	17.10
Sugarbeets	2006	Minnesota	D70 Southwest	4,400	4,400	23.4	103,000	16.60
Sugarbeets	2006	Minnesota	D98 Combined Districts	400	400	19.3	7,900	17.20
Sugarbeets	**2006**	**Minnesota**	**State Total**	**504,000**	**477,000**	**24.9**	**11,877,000**	**17.60**
Sugarbeets	2006	Montana	Dawson	2,930	2,820	20.9	59,000	17.26
Sugarbeets	2006	Montana	Richland	15,530	15,450	25.0	387,000	17.58
Sugarbeets	2006	Montana	Roosevelt	2,180	2,160	26.4	57,000	17.87
Sugarbeets	2006	Montana	D30 Northeast	20,640	20,430	24.6	503,000	17.56
Sugarbeets	2006	Montana	Big Horn	9,880	7,900	31.0	245,000	15.51
Sugarbeets	2006	Montana	Carbon	4,560	4,490	24.9	112,000	16.29
Sugarbeets	2006	Montana	Treasure	3,660	3,090	31.4	97,000	15.70
Sugarbeets	2006	Montana	Yellowstone	9,420	7,830	28.2	220,500	15.61
Sugarbeets	2006	Montana	D80 Combined Counties	320	260	32.9	9,200	16.32
Sugarbeets	2006	Montana	D80 South Central	27,860	23,500	24.0	563,700	15.71
Sugarbeets	2006	Montana	Custer	1,160	1,010	27.1	27,400	16.64
Sugarbeets	2006	Montana	Prairie	1,600	1,570	21.8	34,300	17.78
Sugarbeets	2006	Montana	Rosebud	2,340	1,900	32.4	61,600	15.92
Sugarbeets	2006	Montana	D90 Southeast	5,100	4,480	27.5	123,500	16.56
Sugarbeets	**2006**	**Montana**	**State Total**	**53,600**	**48,500**	**27.0**	**1,310,000**	**16.50**
Sugarbeets	2006	Nebraska	Banner	800	700	16.4	11,500	17.76
Sugarbeets	2006	Nebraska	Box Butte	23,000	22,700	23.0	521,700	17.51
Sugarbeets	2006	Nebraska	Cheyenne	2,900	2,900	24.4	70,900	17.98
Sugarbeets	2006	Nebraska	Deuel	800	800	23.8	19,000	16.66
Sugarbeets	2006	Nebraska	Kimball	4,800	4,300	21.2	91,300	17.70
Sugarbeets	2006	Nebraska	Morrill	5,400	5,100	23.3	118,700	16.16
Sugarbeets	2006	Nebraska	Scotts Bluff	11,500	10,100	23.0	231,500	16.22
Sugarbeets	2006	Nebraska	Sheridan	3,700	3,000	22.4	67,100	17.06
Sugarbeets	2006	Nebraska	D10 Combined Counties	1,000	900	26.1	23,500	16.97
Sugarbeets	2006	Nebraska	D10 Northwest	55,700	50,500	22.9	1,155,500	17.11
Sugarbeets	2006	Nebraska	Chase	3,800	3,800	28.4	108,100	15.40
Sugarbeets	2006	Nebraska	Keith	1,900	1,800	29.6	37,700	16.76
Sugarbeets	2006	Nebraska	Perkins	1,900	1,900	24.1	45,700	16.40

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Nebraska	D70 Southwest	7,800	7,300	26.2	191,500	15.91
Sugarbeets	**2006**	**Nebraska**	**State Total**	**61,300**	**57,800**	**23.3**	**1,347,000**	**16.94**
Sugarbeets	2006	North Dakota	Williams	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	D10 Northwest	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	Grand Forks	32,900	30,400	27.0	822,000	17.66
Sugarbeets	2006	North Dakota	Pembina	79,700	73,200	25.9	1,892,000	15.56
Sugarbeets	2006	North Dakota	Walsh	45,600	41,600	26.3	1,054,000	16.44
Sugarbeets	2006	North Dakota	D30 Northeast	158,200	145,200	26.0	3,769,000	16.94
Sugarbeets	2006	North Dakota	McKenzie	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	D40 West Central	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	Cass	28,700	24,700	26.4	651,000	17.94
Sugarbeets	2006	North Dakota	Traill	29,200	26,900	27.1	730,000	17.56
Sugarbeets	2006	North Dakota	D60 Combined Counties	200	100	30.0	3,000	17.24
Sugarbeets	2006	North Dakota	D60 East Central	55,100	51,700	26.8	1,384,000	17.78
Sugarbeets	2006	North Dakota	Ransom	100	100	30.0	3,000	16.63
Sugarbeets	2006	North Dakota	Richland	31,300	30,200	25.4	768,000	16.99
Sugarbeets	2006	North Dakota	D90 Southeast	31,400	30,900	25.4	785,000	16.99
Sugarbeets	**2006**	**North Dakota**	**State Total**	**261,000**	**243,000**	**26.0**	**6,318,000**	**16.91**
Sugarbeets	2006	Oregon	Union	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	D30 Northeast	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	Malheur	10,800	10,200	31.3	337,700	16.09
Sugarbeets	2006	Oregon	D90 Southeast	10,800	10,200	31.3	337,700	16.09
Sugarbeets	**2006**	**Oregon**	**State Total**	**13,100**	**13,100**	**30.1**	**394,000**	**17.15**
Sugarbeets	2006	Washington	Benton	2,000	2,000	37.0	74,000	16.40
Sugarbeets	2006	Washington	D20 Central	2,000	2,000	37.0	74,000	16.40
Sugarbeets	**2006**	**Washington**	**State Total**	**2,000**	**2,000**	**37.0**	**74,000**	**16.40**
Sugarbeets	2006	Wyoming	Big Horn	12,400	11,300	18.0	203,500	17.00
Sugarbeets	2006	Wyoming	Fremont	2,900	2,200	18.7	41,200	17.13
Sugarbeets	2006	Wyoming	Park	12,700	12,600	22.2	280,000	17.10
Sugarbeets	2006	Wyoming	Washakie	9,400	9,100	19.0	176,000	17.23
Sugarbeets	2006	Wyoming	D10 Northwest	37,400	35,200	20.0	703,000	17.10
Sugarbeets	2006	Wyoming	Goshen	1,600	1,400	21.9	30,600	17.35
Sugarbeets	2006	Wyoming	Laramie	1,000	900	20.7	18,600	17.48
Sugarbeets	2006	Wyoming	Platte	2,800	2,600	17.6	45,800	15.27
Sugarbeets	2006	Wyoming	D80 Southeast	5,400	4,900	19.4	95,000	17.61
Sugarbeets	**2006**	**Wyoming**	**State Total**	**42,800**	**40,100**	**19.9**	**798,000**	**17.18**
Sugarbeets	2005	California	Fresno	11,000	10,700	35.6	365,000	14.72
Sugarbeets	2005	California	Kern	4,700	4,700	40.4	193,000	14.07
Sugarbeets	2005	California	Kings	800	800	28.8	23,000	15.23
Sugarbeets	2005	California	Merced	3,600	3,600	31.1	112,000	15.43
Sugarbeets	2005	California	D31 Combined Counties	900	900	31.1	28,000	14.95
Sugarbeets	2005	California	D31 San Joaquin Valley	21,000	20,700	35.4	733,000	14.66
Sugarbeets	2005	California	Imperial	23,400	23,400	35.6	903,000	15.66
Sugarbeets	2005	California	D80 Southern California	23,400	23,400	35.6	903,000	15.66
Sugarbeets	**2005**	**California**	**State Total**	**44,400**	**44,100**	**37.1**	**1,636,000**	**15.79**
Sugarbeets	2005	Colorado	Boulder	700	600	25.3	15,200	16.83
Sugarbeets	2005	Colorado	Larimer	2,700	2,700	21.5	58,100	16.86
Sugarbeets	2005	Colorado	Logan	4,600	4,300	21.9	94,200	15.06
Sugarbeets	2005	Colorado	Morgan	2,400	2,200	26.0	57,100	15.43
Sugarbeets	2005	Colorado	Sedgwick	1,900	1,800	21.9	39,400	16.01
Sugarbeets	2005	Colorado	Weld	13,700	13,300	25.3	336,000	16.13
Sugarbeets	2005	Colorado	D20 Northeast	25,900	24,900	24.1	600,000	15.98
Sugarbeets	2005	Colorado	Adams	400	400	21.5	8,600	16.51
Sugarbeets	2005	Colorado	Kit Carson	500	500	23.8	11,900	15.34
Sugarbeets	2005	Colorado	Phillips	2,800	2,800	25.0	69,900	15.77
Sugarbeets	2005	Colorado	Washington	1,400	1,300	22.8	29,600	15.38
Sugarbeets	2005	Colorado	Yuma	5,400	4,400	25.7	113,000	15.48
Sugarbeets	2005	Colorado	D60 East Central	10,500	9,400	24.8	233,000	15.67
Sugarbeets	**2005**	**Colorado**	**State Total**	**36,400**	**34,300**	**24.3**	**833,000**	**15.87**
Sugarbeets	2005	Idaho	Ada	2,900	2,800	30.0	84,000	16.48
Sugarbeets	2005	Idaho	Canyon	10,100	9,900	28.9	286,000	16.45
Sugarbeets	2005	Idaho	Elmore	7,700	7,600	25.8	196,000	17.43
Sugarbeets	2005	Idaho	Owyhee	5,200	4,800	29.2	140,000	15.66
Sugarbeets	2005	Idaho	Payette	1,400	1,300	28.5	37,000	16.23
Sugarbeets	2005	Idaho	Washington	1,500	1,400	30.7	43,000	16.32
Sugarbeets	2005	Idaho	D70 Combined Counties	200	200	20.0	4,000	16.26
Sugarbeets	2005	Idaho	D70 Southwest	29,000	28,000	28.6	800,000	16.72
Sugarbeets	2005	Idaho	Cassia	30,600	30,200	26.8	817,000	17.84
Sugarbeets	2005	Idaho	Gooding	2,000	2,000	24.0	48,000	17.10
Sugarbeets	2005	Idaho	Jerome	14,000	13,900	25.2	350,000	17.90
Sugarbeets	2005	Idaho	Lincoln	8,000	7,800	24.0	187,000	17.65
Sugarbeets	2005	Idaho	Minidoka	42,600	42,400	26.0	1,104,000	17.82
Sugarbeets	2005	Idaho	Twin Falls	10,400	10,400	26.3	274,000	17.49

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Michigan	Saginaw	17,800	16,900	22.4	378,000	17.90
Sugarbeets	2006	Michigan	Sanilac	20,200	20,100	24.8	495,000	17.30
Sugarbeets	2006	Michigan	Tuscola	21,100	21,000	24.6	514,000	15.20
Sugarbeets	2006	Michigan	D80 East Central	132,000	131,500	25.9	3,140,000	15.10
Sugarbeets	2006	Michigan	Clinton	1,500	1,500	18.7	28,000	15.30
Sugarbeets	2006	Michigan	Ionia	500	500	22.0	11,000	21.10
Sugarbeets	2006	Michigan	Shiawassee	800	800	20.0	16,000	17.60
Sugarbeets	2006	Michigan	D80 South Central	2,800	2,800	19.6	55,000	15.70
Sugarbeets	2006	Michigan	Lapeer	900	900	24.4	22,000	17.30
Sugarbeets	2006	Michigan	D90 Combined Counties	1,300	1,300	20.8	27,000	17.20
Sugarbeets	2006	Michigan	D90 Southeast	2,300	2,200	22.3	49,000	17.20
Sugarbeets	**2006**	**Michigan**	**State Total**	**155,000**	**154,000**	**23.2**	**3,573,000**	**16.10**
Sugarbeets	2006	Minnesota	Becker	10,400	9,800	27.2	266,500	15.40
Sugarbeets	2006	Minnesota	Clay	56,400	53,700	28.9	1,557,100	15.10
Sugarbeets	2006	Minnesota	Kittson	38,500	35,100	23.6	525,500	19.00
Sugarbeets	2006	Minnesota	Mahnomen	5,100	4,400	24.1	105,900	15.20
Sugarbeets	2006	Minnesota	Marshall	45,700	41,500	22.9	949,300	15.50
Sugarbeets	2006	Minnesota	Norman	46,200	42,100	26.3	1,106,200	17.80
Sugarbeets	2006	Minnesota	Polk	102,400	93,300	24.6	2,314,500	15.00
Sugarbeets	2006	Minnesota	Red Lake	1,900	1,700	22.6	38,700	17.70
Sugarbeets	2006	Minnesota	D10 Combined Counties	400	400	22.3	8,900	17.90
Sugarbeets	2006	Minnesota	D10 Northwest	307,000	281,000	24.8	6,982,500	16.20
Sugarbeets	2006	Minnesota	Chippewa	32,200	32,200	23.2	747,300	16.50
Sugarbeets	2006	Minnesota	Grant	11,600	11,500	23.4	269,400	16.80
Sugarbeets	2006	Minnesota	Otter Tail	4,400	4,300	27.4	118,000	16.80
Sugarbeets	2006	Minnesota	Pope	3,800	3,800	24.8	92,400	16.90
Sugarbeets	2006	Minnesota	Stevens	4,100	4,100	25.5	104,700	17.00
Sugarbeets	2006	Minnesota	Swift	5,900	5,900	23.8	140,700	16.80
Sugarbeets	2006	Minnesota	Traverse	9,600	9,500	24.6	234,000	16.80
Sugarbeets	2006	Minnesota	Wilkin	50,000	50,400	26.7	1,343,400	17.20
Sugarbeets	2006	Minnesota	Yellow Medicine	3,800	3,800	23.2	88,700	16.70
Sugarbeets	2006	Minnesota	D40 Combined Counties	1,100	1,100	23.8	26,200	16.90
Sugarbeets	2006	Minnesota	D40 West Central	127,000	125,200	25.0	3,159,500	16.90
Sugarbeets	2006	Minnesota	Kandiyohi	16,400	16,300	25.6	416,500	16.80
Sugarbeets	2006	Minnesota	McLeod	2,700	2,700	22.6	61,000	16.90
Sugarbeets	2006	Minnesota	Meeker	2,300	2,300	25.5	58,600	16.80
Sugarbeets	2006	Minnesota	Renville	39,400	39,300	24.8	975,400	16.70
Sugarbeets	2006	Minnesota	Sibley	2,300	2,300	25.4	58,500	16.80
Sugarbeets	2006	Minnesota	Stearns	2,100	2,100	26.2	55,000	16.90
Sugarbeets	2006	Minnesota	D60 Central	65,200	65,000	25.0	1,625,100	16.70
Sugarbeets	2006	Minnesota	Redwood	3,600	3,300	23.3	68,900	16.60
Sugarbeets	2006	Minnesota	D70 Combined Counties	600	600	24.2	14,500	17.10
Sugarbeets	2006	Minnesota	D70 Southwest	4,400	4,400	23.4	103,000	16.60
Sugarbeets	2006	Minnesota	D98 Combined Districts	400	400	15.3	7,300	17.20
Sugarbeets	**2006**	**Minnesota**	**State Total**	**504,000**	**477,000**	**24.9**	**11,877,000**	**17.60**
Sugarbeets	2006	Montana	Dawson	2,930	2,830	20.9	59,000	17.26
Sugarbeets	2006	Montana	Richland	15,830	15,450	25.0	387,000	17.56
Sugarbeets	2006	Montana	Roosevelt	2,180	2,160	26.4	57,000	17.67
Sugarbeets	2006	Montana	D30 Northeast	20,640	20,430	24.6	503,000	17.55
Sugarbeets	2006	Montana	Big Horn	9,860	7,900	31.0	245,000	15.51
Sugarbeets	2006	Montana	Carbon	4,560	4,490	24.9	112,000	16.29
Sugarbeets	2006	Montana	Treasure	3,680	3,090	31.4	97,000	15.70
Sugarbeets	2006	Montana	Yellowstone	9,420	7,230	28.2	220,500	15.81
Sugarbeets	2006	Montana	D80 Combined Counties	320	280	32.9	9,200	16.32
Sugarbeets	2006	Montana	D80 South Central	27,860	23,590	29.0	653,700	15.71
Sugarbeets	2006	Montana	Custer	1,160	1,010	27.1	27,400	16.64
Sugarbeets	2006	Montana	Prairie	1,600	1,570	21.8	34,300	17.76
Sugarbeets	2006	Montana	Rosebud	2,340	1,900	32.4	61,600	15.92
Sugarbeets	2006	Montana	D90 Southeast	5,100	4,420	27.8	123,300	16.66
Sugarbeets	**2006**	**Montana**	**State Total**	**53,600**	**48,500**	**27.0**	**1,310,000**	**16.50**
Sugarbeets	2006	Nebraska	Banner	800	700	16.4	11,500	17.76
Sugarbeets	2006	Nebraska	Box Butte	23,000	22,700	23.0	521,700	17.51
Sugarbeets	2006	Nebraska	Cheyenne	2,900	2,900	24.4	70,900	17.98
Sugarbeets	2006	Nebraska	Deuel	800	800	23.8	19,000	16.66
Sugarbeets	2006	Nebraska	Kimball	4,000	4,300	21.2	91,300	17.70
Sugarbeets	2006	Nebraska	Morrill	5,400	5,100	23.3	118,700	16.16
Sugarbeets	2006	Nebraska	Scotts Bluff	11,500	10,100	23.0	231,500	16.22
Sugarbeets	2006	Nebraska	Sheridan	3,700	3,000	22.4	67,100	17.09
Sugarbeets	2006	Nebraska	D10 Combined Counties	1,000	900	26.1	23,500	16.97
Sugarbeets	2006	Nebraska	D10 Northwest	53,700	50,500	22.9	1,155,500	17.11
Sugarbeets	2006	Nebraska	Chase	3,800	3,800	28.4	108,100	15.48
Sugarbeets	2006	Nebraska	Keith	1,900	1,800	23.8	37,700	16.76
Sugarbeets	2006	Nebraska	Perkins	1,900	1,900	24.1	45,700	16.40

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Nebraska	D70 Southwest	7,600	7,300	26.2	191,500	15.91
Sugarbeets	**2006**	**Nebraska**	**State Total**	**61,300**	**57,800**	**23.3**	**1,347,000**	**16.94**
Sugarbeets	2006	North Dakota	Williams	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	D10 Northwest	4,500	4,500	23.8	107,000	17.89
Sugarbeets	2006	North Dakota	Grand Forks	32,900	30,400	27.0	822,000	17.65
Sugarbeets	2006	North Dakota	Pembina	79,700	73,200	25.9	1,893,000	16.59
Sugarbeets	2006	North Dakota	Walsh	45,600	41,600	25.3	1,054,000	16.44
Sugarbeets	2006	North Dakota	D20 Northeast	158,200	145,200	26.0	3,782,000	16.94
Sugarbeets	2006	North Dakota	McKenzie	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	D40 West Central	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	Cass	26,700	24,700	26.4	651,000	17.04
Sugarbeets	2006	North Dakota	Traill	29,200	26,900	27.1	732,000	17.58
Sugarbeets	2006	North Dakota	D60 Combined Counties	200	100	30.0	3,000	17.24
Sugarbeets	2006	North Dakota	D60 East Central	55,100	51,700	28.8	1,354,000	17.75
Sugarbeets	2006	North Dakota	Ransom	100	100	30.0	3,000	16.83
Sugarbeets	2006	North Dakota	Richland	31,300	30,200	25.4	763,000	16.99
Sugarbeets	2006	North Dakota	D60 Southeast	31,400	30,900	25.4	785,000	16.99
Sugarbeets	**2006**	**North Dakota**	**State Total**	**261,000**	**243,000**	**26.0**	**6,318,000**	**16.91**
Sugarbeets	2006	Oregon	Union	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	D30 Northeast	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	Malheur	10,800	10,800	31.3	337,700	16.09
Sugarbeets	2006	Oregon	D80 Southeast	10,800	10,800	31.3	337,700	16.09
Sugarbeets	**2006**	**Oregon**	**State Total**	**13,100**	**13,100**	**30.1**	**394,000**	**17.15**
Sugarbeets	2006	Washington	Benton	2,000	2,000	37.0	74,000	16.40
Sugarbeets	2006	Washington	D20 Central	2,000	2,000	37.0	74,000	16.40
Sugarbeets	**2006**	**Washington**	**State Total**	**2,000**	**2,000**	**37.0**	**74,000**	**16.40**
Sugarbeets	2006	Wyoming	Big Horn	12,400	11,300	18.0	203,500	17.00
Sugarbeets	2006	Wyoming	Fremont	2,900	2,200	18.7	41,200	17.13
Sugarbeets	2006	Wyoming	Park	12,700	12,600	22.2	280,000	17.10
Sugarbeets	2006	Wyoming	Washakie	9,400	9,100	19.6	178,000	17.23
Sugarbeets	2006	Wyoming	D10 Northwest	37,400	35,200	20.0	703,000	17.10
Sugarbeets	2006	Wyoming	Goshen	1,800	1,400	21.9	30,800	17.35
Sugarbeets	2006	Wyoming	Laramie	1,000	900	20.7	18,600	17.48
Sugarbeets	2006	Wyoming	Platte	2,800	2,600	17.6	45,800	16.27
Sugarbeets	2006	Wyoming	D50 Southeast	5,400	4,900	19.4	95,000	17.61
Sugarbeets	**2006**	**Wyoming**	**State Total**	**42,800**	**40,100**	**19.9**	**798,000**	**17.18**
Sugarbeets	2005	California	Fresno	11,000	10,700	35.6	380,000	14.72
Sugarbeets	2005	California	Kern	4,700	4,700	40.4	190,000	14.07
Sugarbeets	2005	California	Kings	800	800	28.8	23,000	15.22
Sugarbeets	2005	California	Merced	3,600	3,600	31.1	112,000	15.43
Sugarbeets	2005	California	D51 Combined Counties	900	900	31.1	28,000	14.95
Sugarbeets	2005	California	D51 San Joaquin Valley	21,000	20,700	35.4	733,000	14.66
Sugarbeets	2005	California	Imperial	23,400	23,400	38.6	903,000	16.66
Sugarbeets	2005	California	D80 Southern California	23,400	23,400	38.6	903,000	16.66
Sugarbeets	**2005**	**California**	**State Total**	**44,400**	**44,100**	**37.1**	**1,636,000**	**15.79**
Sugarbeets	2005	Colorado	Boulder	700	600	25.3	15,200	16.83
Sugarbeets	2005	Colorado	Larimer	2,700	2,700	21.5	55,100	16.88
Sugarbeets	2005	Colorado	Logan	4,500	4,300	21.9	94,200	15.08
Sugarbeets	2005	Colorado	Morgan	2,400	2,200	26.0	57,100	15.43
Sugarbeets	2005	Colorado	Sedgwick	1,900	1,800	21.9	39,400	16.01
Sugarbeets	2005	Colorado	Weld	13,700	13,300	25.3	332,000	16.13
Sugarbeets	2005	Colorado	D20 Northeast	25,900	24,900	24.1	600,000	15.98
Sugarbeets	2005	Colorado	Adams	400	400	21.5	8,600	16.51
Sugarbeets	2005	Colorado	Kit Carson	500	500	23.8	11,900	15.34
Sugarbeets	2005	Colorado	Phillips	2,800	2,800	25.0	69,800	15.77
Sugarbeets	2005	Colorado	Washington	1,400	1,300	22.8	29,600	15.38
Sugarbeets	2005	Colorado	Yuma	5,400	4,400	25.7	113,000	15.45
Sugarbeets	2005	Colorado	D60 East Central	10,500	9,400	24.8	233,000	15.57
Sugarbeets	**2005**	**Colorado**	**State Total**	**36,400**	**34,300**	**24.3**	**833,000**	**15.87**
Sugarbeets	2005	Idaho	Ada	2,900	2,200	30.0	64,000	16.48
Sugarbeets	2005	Idaho	Canyon	10,100	9,900	29.9	296,000	16.45
Sugarbeets	2005	Idaho	Elmore	7,700	7,600	25.8	196,000	17.43
Sugarbeets	2005	Idaho	Owyhee	5,200	4,800	29.2	140,000	15.66
Sugarbeets	2005	Idaho	Payette	1,400	1,300	28.5	37,000	16.23
Sugarbeets	2005	Idaho	Washington	1,500	1,400	30.7	43,000	15.32
Sugarbeets	2005	Idaho	D70 Combined Counties	200	200	20.0	4,000	16.26
Sugarbeets	2005	Idaho	D70 Southwest	29,000	28,000	28.6	800,000	16.72
Sugarbeets	2005	Idaho	Cassia	30,600	30,600	26.2	517,000	17.64
Sugarbeets	2005	Idaho	Gooding	2,000	2,000	24.0	48,000	17.10
Sugarbeets	2005	Idaho	Jerome	14,000	13,900	25.2	350,000	17.90
Sugarbeets	2005	Idaho	Lincoln	5,000	7,200	24.0	167,000	17.85
Sugarbeets	2005	Idaho	Minidoka	42,500	42,400	26.0	1,104,000	17.62
Sugarbeets	2005	Idaho	Twin Falls	10,400	10,400	26.3	274,000	17.49

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Michigan	Saginaw	17,000	16,900	22.4	378,000	17.90
Sugarbeets	2006	Michigan	Sanilac	20,200	20,100	24.8	498,000	17.30
Sugarbeets	2006	Michigan	Tuscola	21,100	21,000	24.5	514,000	15.20
Sugarbeets	2006	Michigan	D60 East Central	132,000	131,500	23.9	3,140,000	16.10
Sugarbeets	2006	Michigan	Clinton	1,500	1,500	16.7	25,000	15.30
Sugarbeets	2006	Michigan	Ionia	500	500	22.0	11,000	21.10
Sugarbeets	2006	Michigan	Shiawassee	800	800	20.0	16,000	17.60
Sugarbeets	2006	Michigan	D80 South Central	2,800	2,800	19.6	55,000	15.70
Sugarbeets	2006	Michigan	Lapeer	900	900	24.4	22,000	17.30
Sugarbeets	2006	Michigan	D90 Combined Counties	1,300	1,300	20.2	27,000	17.20
Sugarbeets	2006	Michigan	D90 Southeast	2,200	2,200	22.3	49,000	17.20
Sugarbeets	**2006**	**Michigan**	**State Total**	**155,000**	**154,000**	**23.2**	**3,573,000**	**16.10**
Sugarbeets	2006	Minnesota	Becker	10,400	9,800	27.2	266,600	16.40
Sugarbeets	2006	Minnesota	Clay	56,400	52,700	28.9	1,567,100	16.10
Sugarbeets	2006	Minnesota	Kittson	35,600	35,100	23.6	825,300	19.00
Sugarbeets	2006	Minnesota	Mahnomen	5,100	4,400	24.1	105,900	16.20
Sugarbeets	2006	Minnesota	Marshall	45,700	41,500	22.9	949,500	16.50
Sugarbeets	2006	Minnesota	Norman	46,200	42,100	26.3	1,106,200	17.80
Sugarbeets	2006	Minnesota	Polk	102,400	93,300	24.8	2,314,500	15.90
Sugarbeets	2006	Minnesota	Red Lake	1,900	1,700	22.8	38,700	17.70
Sugarbeets	2006	Minnesota	D10 Combined Counties	400	400	22.3	9,000	17.90
Sugarbeets	2006	Minnesota	D10 Northwest	307,000	281,000	24.8	6,992,500	16.20
Sugarbeets	2006	Minnesota	Chippewa	32,200	32,200	23.2	747,300	16.50
Sugarbeets	2006	Minnesota	Grant	11,800	11,500	23.4	269,400	16.80
Sugarbeets	2006	Minnesota	Otter Tail	4,400	4,300	27.4	118,000	16.80
Sugarbeets	2006	Minnesota	Pope	3,800	3,600	24.8	89,400	16.90
Sugarbeets	2006	Minnesota	Stevens	4,100	4,100	26.5	104,700	17.00
Sugarbeets	2006	Minnesota	Swift	6,900	6,900	23.8	148,700	16.60
Sugarbeets	2006	Minnesota	Traverse	9,600	9,500	24.6	234,000	16.90
Sugarbeets	2006	Minnesota	Wilkin	59,900	50,400	26.7	1,343,400	17.20
Sugarbeets	2006	Minnesota	Yellow Medicine	3,600	3,600	23.8	85,700	16.70
Sugarbeets	2006	Minnesota	D40 Combined Counties	1,100	1,100	23.8	26,200	16.90
Sugarbeets	2006	Minnesota	D40 West Central	127,000	126,200	25.0	3,153,500	16.90
Sugarbeets	2006	Minnesota	Kandiyohi	16,400	16,300	25.6	416,600	16.80
Sugarbeets	2006	Minnesota	McLeod	2,700	2,700	22.6	61,000	16.90
Sugarbeets	2006	Minnesota	Meeker	2,300	2,300	25.5	58,600	16.80
Sugarbeets	2006	Minnesota	Renville	39,400	38,300	24.8	975,400	16.70
Sugarbeets	2006	Minnesota	Sibley	2,300	2,300	25.4	58,500	16.80
Sugarbeets	2006	Minnesota	Stearns	2,100	2,100	26.2	55,000	16.30
Sugarbeets	2006	Minnesota	D50 Central	66,200	66,000	25.0	1,625,100	16.70
Sugarbeets	2006	Minnesota	Redwood	3,800	3,800	23.3	88,500	16.50
Sugarbeets	2006	Minnesota	D70 Combined Counties	600	600	24.2	14,500	17.10
Sugarbeets	2006	Minnesota	D70 Southwest	4,400	4,400	23.4	103,000	16.60
Sugarbeets	2006	Minnesota	D98 Combined Districts	400	400	18.3	7,300	17.20
Sugarbeets	**2006**	**Minnesota**	**State Total**	**504,000**	**477,000**	**24.9**	**11,877,000**	**17.60**
Sugarbeets	2006	Montana	Dawson	2,830	2,820	20.9	59,000	17.26
Sugarbeets	2006	Montana	Richland	15,530	15,460	25.0	387,000	17.58
Sugarbeets	2006	Montana	Roosevelt	2,185	2,160	26.4	57,000	17.67
Sugarbeets	2006	Montana	D30 Northeast	20,840	20,430	24.6	503,000	17.55
Sugarbeets	2006	Montana	Big Horn	8,880	7,900	31.0	245,000	15.51
Sugarbeets	2006	Montana	Carbon	4,660	4,490	24.9	112,000	16.26
Sugarbeets	2006	Montana	Treasure	3,680	3,090	31.4	97,000	15.70
Sugarbeets	2006	Montana	Yellowstone	9,420	7,830	28.2	220,500	15.61
Sugarbeets	2006	Montana	D80 Combined Counties	320	280	32.8	9,200	16.32
Sugarbeets	2006	Montana	D80 South Central	27,660	23,590	29.0	683,700	15.71
Sugarbeets	2006	Montana	Custer	1,160	1,010	27.1	27,400	16.64
Sugarbeets	2006	Montana	Prairie	1,600	1,370	21.3	34,300	17.75
Sugarbeets	2006	Montana	Rosebud	2,345	1,900	32.4	61,600	15.92
Sugarbeets	2006	Montana	D90 Southeast	5,109	4,480	27.5	123,300	16.66
Sugarbeets	**2006**	**Montana**	**State Total**	**53,600**	**48,500**	**27.0**	**1,310,000**	**16.50**
Sugarbeets	2006	Nebraska	Banner	800	700	16.4	11,500	17.76
Sugarbeets	2006	Nebraska	Box Butte	23,000	22,700	23.0	521,700	17.51
Sugarbeets	2006	Nebraska	Cheyenne	2,900	2,900	24.4	70,900	17.08
Sugarbeets	2006	Nebraska	Deuel	800	800	23.8	19,000	16.86
Sugarbeets	2006	Nebraska	Kimball	4,800	4,300	21.2	91,300	17.70
Sugarbeets	2006	Nebraska	Morrill	5,400	5,100	23.3	118,700	16.16
Sugarbeets	2006	Nebraska	Scotts Bluff	11,500	10,100	23.0	231,500	16.22
Sugarbeets	2006	Nebraska	Sheridan	3,700	3,000	22.4	67,100	17.06
Sugarbeets	2006	Nebraska	D10 Combined Counties	1,000	900	26.1	23,500	16.97
Sugarbeets	2006	Nebraska	D10 Northwest	53,700	50,500	22.9	1,155,500	17.11
Sugarbeets	2006	Nebraska	Chase	3,800	3,800	26.4	100,100	15.40
Sugarbeets	2006	Nebraska	Keith	1,900	1,600	23.6	37,700	16.76
Sugarbeets	2006	Nebraska	Perkins	1,900	1,900	24.1	45,700	16.40

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2006	Nebraska	D70 Southwest	7,600	7,300	26.2	191,500	15.91
Sugarbeets	**2006**	**Nebraska**	**State Total**	**61,300**	**57,900**	**23.3**	**1,347,000**	**16.94**
Sugarbeets	2006	North Dakota	Williams	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	D10 Northwest	4,500	4,500	23.8	107,000	17.99
Sugarbeets	2006	North Dakota	Grand Forks	32,900	30,400	27.0	822,000	17.65
Sugarbeets	2006	North Dakota	Pembina	79,700	73,200	25.9	1,893,000	15.50
Sugarbeets	2006	North Dakota	Walsh	45,600	41,600	25.3	1,054,000	15.44
Sugarbeets	2006	North Dakota	D20 Northeast	158,200	145,200	26.0	3,769,000	15.34
Sugarbeets	2006	North Dakota	McKenzie	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	D40 West Central	10,800	10,700	25.4	272,000	17.76
Sugarbeets	2006	North Dakota	Cass	25,700	24,700	26.4	651,000	17.94
Sugarbeets	2006	North Dakota	Traill	29,200	26,900	27.1	730,000	17.56
Sugarbeets	2006	North Dakota	D60 Combined Counties	200	100	30.0	3,000	17.24
Sugarbeets	2006	North Dakota	D60 East Central	56,100	51,700	26.8	1,384,000	17.75
Sugarbeets	2006	North Dakota	Ransom	100	100	30.0	3,000	16.83
Sugarbeets	2006	North Dakota	Richland	31,300	30,800	25.4	783,000	16.99
Sugarbeets	2006	North Dakota	D90 Southeast	31,400	30,900	25.4	785,000	16.99
Sugarbeets	**2006**	**North Dakota**	**State Total**	**261,000**	**243,000**	**26.0**	**6,318,000**	**16.01**
Sugarbeets	2006	Oregon	Union	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	D30 Northeast	2,300	2,300	24.5	56,300	17.60
Sugarbeets	2006	Oregon	Malheur	10,800	10,800	31.3	337,700	16.09
Sugarbeets	2006	Oregon	D80 Southeast	10,800	10,800	31.3	337,700	16.09
Sugarbeets	**2006**	**Oregon**	**State Total**	**13,100**	**13,100**	**30.1**	**394,000**	**17.15**
Sugarbeets	2006	Washington	Benton	2,000	2,000	37.0	74,000	16.40
Sugarbeets	2006	Washington	D20 Central	2,000	2,000	37.0	74,000	16.40
Sugarbeets	**2006**	**Washington**	**State Total**	**2,000**	**2,000**	**37.0**	**74,000**	**16.40**
Sugarbeets	2006	Wyoming	Big Horn	12,400	11,300	18.0	203,500	17.00
Sugarbeets	2006	Wyoming	Fremont	2,900	2,200	18.7	41,200	17.13
Sugarbeets	2006	Wyoming	Park	12,700	12,600	22.2	280,000	17.10
Sugarbeets	2006	Wyoming	Washakie	9,400	9,100	19.6	178,000	17.23
Sugarbeets	2006	Wyoming	D10 Northwest	37,400	35,200	20.0	703,000	17.10
Sugarbeets	2006	Wyoming	Goshen	1,600	1,400	21.9	30,600	17.35
Sugarbeets	2006	Wyoming	Laramie	1,000	900	20.7	18,600	17.46
Sugarbeets	2006	Wyoming	Platte	2,800	2,600	17.6	45,800	16.27
Sugarbeets	2006	Wyoming	D80 Southeast	5,400	4,900	19.4	95,000	17.81
Sugarbeets	**2006**	**Wyoming**	**State Total**	**42,800**	**40,100**	**19.9**	**798,000**	**17.19**
Sugarbeets	2005	California	Fresno	11,000	10,700	35.5	382,000	14.72
Sugarbeets	2005	California	Kern	4,700	4,700	40.4	190,000	14.07
Sugarbeets	2005	California	Kings	800	800	28.8	23,000	15.22
Sugarbeets	2005	California	Merced	3,600	3,600	31.1	112,000	15.43
Sugarbeets	2005	California	D51 Combined Counties	900	900	31.1	28,000	14.06
Sugarbeets	2005	California	D51 San Joaquin Valley	21,000	20,700	35.4	733,000	14.66
Sugarbeets	2005	California	Imperial	23,400	23,400	38.6	903,000	16.68
Sugarbeets	2005	California	D80 Southern California	23,400	23,400	38.6	903,000	16.68
Sugarbeets	**2005**	**California**	**State Total**	**44,400**	**44,100**	**37.1**	**1,636,000**	**15.79**
Sugarbeets	2005	Colorado	Boulder	700	600	25.3	15,200	16.83
Sugarbeets	2005	Colorado	Larimer	2,700	2,700	21.5	58,100	16.86
Sugarbeets	2005	Colorado	Logan	4,500	4,300	21.9	94,200	15.06
Sugarbeets	2005	Colorado	Morgan	2,400	2,200	26.0	57,100	15.43
Sugarbeets	2005	Colorado	Sedgwick	1,900	1,800	21.9	39,400	16.01
Sugarbeets	2005	Colorado	Weld	13,700	13,300	25.3	336,000	16.13
Sugarbeets	2005	Colorado	D20 Northeast	25,900	24,900	24.1	600,000	15.99
Sugarbeets	2005	Colorado	Adams	400	400	21.5	8,600	16.51
Sugarbeets	2005	Colorado	Kit Carson	500	500	33.6	16,800	15.34
Sugarbeets	2005	Colorado	Phillips	2,800	2,800	25.0	69,900	15.77
Sugarbeets	2005	Colorado	Washington	1,400	1,300	22.8	29,600	15.39
Sugarbeets	2005	Colorado	Yuma	5,400	4,400	25.7	113,000	15.45
Sugarbeets	2005	Colorado	D60 East Central	10,500	9,400	24.8	233,000	15.67
Sugarbeets	**2005**	**Colorado**	**State Total**	**36,400**	**34,300**	**24.3**	**833,000**	**15.87**
Sugarbeets	2005	Idaho	Ada	2,900	2,800	30.0	84,000	16.48
Sugarbeets	2005	Idaho	Canyon	10,100	9,900	29.9	296,000	16.43
Sugarbeets	2005	Idaho	Elmore	7,700	7,600	25.8	196,000	17.43
Sugarbeets	2005	Idaho	Owyhee	5,200	4,800	29.2	140,000	15.68
Sugarbeets	2005	Idaho	Payette	1,400	1,300	28.5	37,000	16.23
Sugarbeets	2005	Idaho	Washington	1,500	1,400	30.7	43,000	15.32
Sugarbeets	2005	Idaho	D70 Combined Counties	200	200	20.0	4,000	16.26
Sugarbeets	2005	Idaho	D70 Southwest	29,000	28,000	29.6	830,000	16.72
Sugarbeets	2005	Idaho	Cassia	30,600	30,500	28.8	517,000	17.84
Sugarbeets	2005	Idaho	Gooding	2,005	2,000	24.0	45,000	17.10
Sugarbeets	2005	Idaho	Jerome	14,000	13,900	25.2	350,000	17.90
Sugarbeets	2005	Idaho	Lincoln	5,000	7,800	24.0	187,000	17.65
Sugarbeets	2005	Idaho	Minidoka	42,500	42,400	28.0	1,104,000	17.62
Sugarbeets	2005	Idaho	Twin Falls	10,400	10,400	26.3	274,000	17.49

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Idaho	D80 South Central	107,500	107,000	26.0	2,780,000	17.79
Sugarbeets	2005	Idaho	Bingham	19,200	18,200	29.8	541,000	17.69
Sugarbeets	2005	Idaho	Power	13,300	13,200	30.7	405,000	17.59
Sugarbeets	2005	Idaho	D90 East	32,500	32,000	29.6	946,000	17.65
Sugarbeets	**2005**	**Idaho**	**State Total**	**169,000**	**167,000**	**27.1**	**4,526,000**	**17.57**
Sugarbeets	2005	Michigan	D30 Combined Counties	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	D30 Northeast	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	Gladwin	1,000	1,000	23.0	23,000	17.20
Sugarbeets	2005	Michigan	Gratiot	11,000	10,800	20.4	220,000	17.10
Sugarbeets	2005	Michigan	Isabella	900	900	20.0	18,000	16.80
Sugarbeets	2005	Michigan	Midland	3,200	3,200	19.7	63,000	16.20
Sugarbeets	2005	Michigan	Montcalm	1,100	1,100	22.7	25,000	16.70
Sugarbeets	2005	Michigan	D50 Central	17,200	17,000	20.5	349,000	16.90
Sugarbeets	2005	Michigan	Arenac	3,700	3,700	23.5	87,000	17.20
Sugarbeets	2005	Michigan	Bay	14,500	14,000	19.1	268,000	16.50
Sugarbeets	2005	Michigan	Huron	54,500	54,000	22.6	1,220,000	17.10
Sugarbeets	2005	Michigan	Saginaw	16,300	16,200	20.1	326,000	16.80
Sugarbeets	2005	Michigan	Sanilac	20,000	19,800	22.0	436,000	16.80
Sugarbeets	2005	Michigan	Tuscola	21,000	20,600	20.5	423,000	16.90
Sugarbeets	2005	Michigan	D60 East Central	130,000	125,300	21.5	2,700,000	16.90
Sugarbeets	2005	Michigan	Clinton	1,800	1,800	19.4	35,000	17.50
Sugarbeets	2005	Michigan	Ionia	500	500	16.0	8,000	17.90
Sugarbeets	2005	Michigan	Shiawassee	1,000	900	20.0	18,000	17.30
Sugarbeets	2005	Michigan	D80 South Central	3,300	3,200	19.1	61,000	17.50
Sugarbeets	2005	Michigan	Genesee	700	700	20.0	14,000	13.40
Sugarbeets	2005	Michigan	Lapeer	1,000	1,000	20.0	20,000	17.00
Sugarbeets	2005	Michigan	St. Clair	1,200	1,200	17.5	21,000	17.30
Sugarbeets	2005	Michigan	D90 Southeast	2,900	2,900	19.0	55,000	16.20
Sugarbeets	**2005**	**Michigan**	**State Total**	**154,000**	**152,000**	**21.3**	**3,238,000**	**16.90**
Sugarbeets	2005	Minnesota	Becker	10,700	10,000	20.4	203,600	15.20
Sugarbeets	2005	Minnesota	Clay	57,000	56,100	19.8	1,113,000	17.50
Sugarbeets	2005	Minnesota	Kittson	36,600	18,300	11.8	216,300	15.50
Sugarbeets	2005	Minnesota	Mahnomen	5,800	5,600	22.5	125,900	15.10
Sugarbeets	2005	Minnesota	Marshall	47,400	42,600	15.4	656,500	15.10
Sugarbeets	2005	Minnesota	Norman	43,200	42,700	21.2	905,500	17.70
Sugarbeets	2005	Minnesota	Polk	99,100	97,600	20.2	1,974,400	17.80
Sugarbeets	2005	Minnesota	Red Lake	1,200	1,100	18.5	20,300	17.70
Sugarbeets	2005	Minnesota	D10 Combined Counties	400	400	18.5	7,400	17.60
Sugarbeets	2005	Minnesota	D10 Northwest	301,400	275,000	19.0	5,223,500	17.60
Sugarbeets	2005	Minnesota	Chippewa	34,300	34,200	25.0	855,000	15.60
Sugarbeets	2005	Minnesota	Grant	10,200	10,000	14.5	145,200	16.10
Sugarbeets	2005	Minnesota	Otter Tail	3,200	3,100	15.8	48,900	15.90
Sugarbeets	2005	Minnesota	Pope	2,300	2,200	24.7	54,300	16.40
Sugarbeets	2005	Minnesota	Stevens	3,900	3,800	23.5	89,400	16.20
Sugarbeets	2005	Minnesota	Swift	6,100	5,900	25.6	151,100	16.10
Sugarbeets	2005	Minnesota	Traverse	5,800	8,100	14.1	114,500	16.40
Sugarbeets	2005	Minnesota	Wilkin	47,100	45,400	18.3	828,700	16.60
Sugarbeets	2005	Minnesota	Yellow Medicine	2,800	2,700	27.9	75,200	16.00
Sugarbeets	2005	Minnesota	D40 Combined Counties	800	800	25.4	21,100	20.60
Sugarbeets	2005	Minnesota	D40 West Central	119,600	116,200	20.5	2,384,400	16.20
Sugarbeets	2005	Minnesota	Kandiyohi	13,200	13,100	26.3	345,000	15.60
Sugarbeets	2005	Minnesota	McLeod	1,500	1,400	23.0	32,200	15.50
Sugarbeets	2005	Minnesota	Meeker	1,900	1,800	24.8	44,700	15.60
Sugarbeets	2005	Minnesota	Renville	42,100	41,600	25.8	1,074,500	16.40
Sugarbeets	2005	Minnesota	Sibley	3,700	3,600	24.9	89,600	15.00
Sugarbeets	2005	Minnesota	Stearns	2,700	2,600	23.7	61,600	16.00
Sugarbeets	2005	Minnesota	D50 Central	65,100	64,100	25.7	1,647,600	15.50
Sugarbeets	2005	Minnesota	Redwood	3,400	3,300	27.3	90,100	15.40
Sugarbeets	2005	Minnesota	D70 Combined Counties	600	600	24.6	16,700	24.70
Sugarbeets	2005	Minnesota	D70 Southwest	4,200	4,100	28.2	109,900	15.50
Sugarbeets	2005	Minnesota	D90 Combined Districts	700	600	27.8	16,700	15.70
Sugarbeets	**2005**	**Minnesota**	**State Total**	**491,000**	**460,000**	**20.4**	**9,384,000**	**17.00**
Sugarbeets	2005	Montana	Dawson	2,980	2,230	20.7	46,200	16.01
Sugarbeets	2005	Montana	Richland	17,720	16,190	21.2	344,000	15.89
Sugarbeets	2005	Montana	Roosevelt	2,140	2,100	19.9	41,700	19.27
Sugarbeets	2005	Montana	D30 Northeast	22,860	20,520	21.0	431,900	15.56
Sugarbeets	2005	Montana	Big Horn	9,260	8,760	25.9	227,600	16.44
Sugarbeets	2005	Montana	Carbon	4,280	4,120	22.7	93,700	16.82
Sugarbeets	2005	Montana	Treasure	3,210	2,660	26.1	73,000	16.53
Sugarbeets	2005	Montana	Yellowstone	8,610	8,460	24.3	206,000	16.59
Sugarbeets	2005	Montana	D80 Combined Counties	200	200	30.0	6,000	16.43
Sugarbeets	2005	Montana	D80 South Central	25,560	24,560	24.9	611,300	16.56
Sugarbeets	2005	Montana	Custer	1,380	1,370	19.3	26,400	15.54

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Idaho	D80 South Central	107,600	107,000	25.0	2,750,000	17.79
Sugarbeets	2005	Idaho	Bingham	19,200	18,200	29.8	541,000	17.69
Sugarbeets	2005	Idaho	Power	13,300	13,200	30.7	405,000	17.59
Sugarbeets	2005	Idaho	D90 East	32,600	32,000	29.6	946,000	17.65
Sugarbeets	**2005**	**Idaho**	**State Total**	**169,000**	**167,000**	**27.1**	**4,526,000**	**17.57**
Sugarbeets	2005	Michigan	D30 Combined Counties	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	D30 Northeast	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	Gladwin	1,000	1,000	23.0	23,000	17.20
Sugarbeets	2005	Michigan	Gratiot	11,000	10,800	20.4	220,000	17.10
Sugarbeets	2005	Michigan	Isabella	900	900	20.0	18,000	16.80
Sugarbeets	2005	Michigan	Midland	3,200	3,200	19.7	63,000	16.20
Sugarbeets	2005	Michigan	Montcalm	1,100	1,100	22.7	25,000	16.70
Sugarbeets	2005	Michigan	D50 Central	17,200	17,000	20.5	349,000	16.90
Sugarbeets	2005	Michigan	Arenac	3,700	3,700	23.5	87,000	17.20
Sugarbeets	2005	Michigan	Bay	14,600	14,000	19.1	268,000	16.50
Sugarbeets	2005	Michigan	Huron	54,600	54,000	22.6	1,220,000	17.10
Sugarbeets	2005	Michigan	Saginaw	16,300	16,200	20.1	326,000	16.80
Sugarbeets	2005	Michigan	Sanilac	20,000	19,200	22.0	436,000	16.80
Sugarbeets	2005	Michigan	Tuscola	21,000	20,600	20.5	423,000	16.90
Sugarbeets	2005	Michigan	D60 East Central	130,000	125,300	21.5	2,760,000	16.90
Sugarbeets	2005	Michigan	Clinton	1,800	1,800	19.4	35,000	17.50
Sugarbeets	2005	Michigan	Ionia	500	500	16.0	8,000	17.90
Sugarbeets	2005	Michigan	Shiawassee	1,000	900	20.0	18,000	17.30
Sugarbeets	2005	Michigan	D80 South Central	3,300	3,200	19.1	61,000	17.60
Sugarbeets	2005	Michigan	Genesee	700	700	20.0	14,000	13.40
Sugarbeets	2005	Michigan	Lapeer	1,000	1,000	20.0	20,000	17.00
Sugarbeets	2005	Michigan	St. Clair	1,200	1,200	17.5	21,000	17.30
Sugarbeets	2005	Michigan	D90 Southeast	2,900	2,900	19.0	55,000	16.20
Sugarbeets	**2005**	**Michigan**	**State Total**	**154,000**	**152,000**	**21.3**	**3,238,000**	**16.90**
Sugarbeets	2005	Minnesota	Becker	10,700	10,000	20.4	203,600	15.20
Sugarbeets	2005	Minnesota	Clay	57,000	56,100	19.8	1,113,000	17.50
Sugarbeets	2005	Minnesota	Kittson	36,600	18,300	11.8	216,300	15.50
Sugarbeets	2005	Minnesota	Mahnomen	5,600	5,600	22.5	125,900	15.10
Sugarbeets	2005	Minnesota	Marshall	47,400	42,900	15.4	659,500	15.10
Sugarbeets	2005	Minnesota	Norman	43,200	42,700	21.2	905,600	17.70
Sugarbeets	2005	Minnesota	Polk	99,100	97,900	20.2	1,974,400	17.80
Sugarbeets	2005	Minnesota	Red Lake	1,200	1,100	18.6	20,300	17.70
Sugarbeets	2005	Minnesota	D10 Combined Counties	400	400	18.5	7,400	17.80
Sugarbeets	2005	Minnesota	D10 Northwest	301,400	275,000	19.0	5,225,500	17.80
Sugarbeets	2005	Minnesota	Chippewa	34,300	34,300	25.0	666,000	15.80
Sugarbeets	2005	Minnesota	Grant	10,200	10,000	14.5	145,200	16.10
Sugarbeets	2005	Minnesota	Otter Tail	3,200	3,100	15.2	48,000	15.90
Sugarbeets	2005	Minnesota	Pope	2,300	2,200	24.7	54,300	16.40
Sugarbeets	2005	Minnesota	Stevens	3,900	3,200	28.5	89,400	16.20
Sugarbeets	2005	Minnesota	Swift	6,100	5,900	25.6	151,100	16.10
Sugarbeets	2005	Minnesota	Traverse	8,800	8,100	14.1	114,500	16.40
Sugarbeets	2005	Minnesota	Wilkin	47,100	45,400	18.3	826,700	16.80
Sugarbeets	2005	Minnesota	Yellow Medicine	2,800	2,700	27.6	75,200	16.00
Sugarbeets	2005	Minnesota	D40 Combined Counties	900	800	26.4	21,100	20.60
Sugarbeets	2005	Minnesota	D40 West Central	119,600	116,200	20.2	2,334,400	16.20
Sugarbeets	2005	Minnesota	Kandiyohi	13,200	13,100	26.3	345,000	15.90
Sugarbeets	2005	Minnesota	McLeod	1,500	1,400	23.0	32,200	15.50
Sugarbeets	2005	Minnesota	Meeker	1,900	1,800	24.2	44,700	15.80
Sugarbeets	2005	Minnesota	Renville	42,100	41,600	25.8	1,074,500	15.40
Sugarbeets	2005	Minnesota	Sibley	3,700	3,600	24.9	89,600	15.00
Sugarbeets	2005	Minnesota	Stearns	2,700	2,600	23.7	61,600	16.00
Sugarbeets	2005	Minnesota	D50 Central	65,100	64,100	25.7	1,647,600	15.50
Sugarbeets	2005	Minnesota	Redwood	3,400	3,300	27.3	90,100	15.40
Sugarbeets	2005	Minnesota	D70 Combined Counties	800	800	24.6	19,700	24.70
Sugarbeets	2005	Minnesota	D70 Southwest	4,200	4,100	26.8	109,500	15.50
Sugarbeets	2005	Minnesota	D90 Combined Districts	700	600	27.8	16,700	15.70
Sugarbeets	**2005**	**Minnesota**	**State Total**	**451,000**	**460,000**	**20.4**	**9,384,000**	**17.00**
Sugarbeets	2005	Montana	Dawson	2,900	2,230	20.7	46,200	16.01
Sugarbeets	2005	Montana	Richland	17,730	16,180	21.2	344,000	15.59
Sugarbeets	2005	Montana	Roosevelt	2,140	2,100	19.9	41,700	16.27
Sugarbeets	2005	Montana	D30 Northeast	22,850	20,520	21.0	431,900	15.69
Sugarbeets	2005	Montana	Big Horn	9,260	8,790	25.9	227,600	16.44
Sugarbeets	2005	Montana	Carbon	4,280	4,120	22.7	93,700	16.82
Sugarbeets	2005	Montana	Treasure	3,210	2,990	26.1	78,000	16.53
Sugarbeets	2005	Montana	Yellowstone	8,610	8,460	24.3	205,000	16.59
Sugarbeets	2005	Montana	D80 Combined Counties	200	200	30.0	6,000	16.43
Sugarbeets	2005	Montana	D80 South Central	25,690	24,560	24.9	611,300	16.56
Sugarbeets	2005	Montana	Custer	1,390	1,370	19.3	26,400	15.54

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Idaho	D80 South Central	107,500	107,000	26.0	2,750,000	17.79
Sugarbeets	2005	Idaho	Bingham	19,200	18,800	28.8	541,000	17.80
Sugarbeets	2005	Idaho	Power	13,300	13,200	30.7	405,000	17.50
Sugarbeets	2005	Idaho	D60 East	32,500	32,000	29.6	946,000	17.65
Sugarbeets	**2005**	**Idaho**	**State Total**	**169,000**	**167,000**	**27.1**	**4,526,000**	**17.57**
Sugarbeets	2005	Michigan	D30 Combined Counties	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	D30 Northeast	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	Gladwin	1,000	1,000	23.0	23,000	17.20
Sugarbeets	2005	Michigan	Gratiot	11,000	10,800	20.4	220,000	17.10
Sugarbeets	2005	Michigan	Isabella	900	900	20.0	18,000	16.80
Sugarbeets	2005	Michigan	Midland	3,200	3,200	19.7	63,000	16.20
Sugarbeets	2005	Michigan	Montcalm	1,100	1,100	22.7	25,000	16.70
Sugarbeets	2005	Michigan	D80 Central	17,200	17,000	20.5	349,000	16.90
Sugarbeets	2005	Michigan	Arenac	3,700	3,700	23.5	87,000	17.20
Sugarbeets	2005	Michigan	Bay	14,600	14,000	19.1	268,000	16.50
Sugarbeets	2005	Michigan	Huron	54,600	54,000	22.6	1,220,000	17.10
Sugarbeets	2005	Michigan	Saginaw	16,300	16,200	20.1	326,000	16.60
Sugarbeets	2005	Michigan	Sanilac	20,000	19,200	22.8	436,000	16.60
Sugarbeets	2005	Michigan	Tuscola	21,000	20,600	20.5	423,000	16.90
Sugarbeets	2005	Michigan	D60 East Central	133,000	125,300	21.6	2,760,000	16.90
Sugarbeets	2005	Michigan	Clinton	1,600	1,200	19.4	35,000	17.50
Sugarbeets	2005	Michigan	Ionia	600	500	18.0	9,000	17.90
Sugarbeets	2005	Michigan	Shiawassee	1,000	900	20.0	18,000	17.30
Sugarbeets	2005	Michigan	D80 South Central	3,300	3,200	19.1	61,000	17.50
Sugarbeets	2005	Michigan	Genesee	700	700	20.0	14,000	13.40
Sugarbeets	2005	Michigan	Lapeer	1,000	1,000	20.0	20,000	17.00
Sugarbeets	2005	Michigan	St. Clair	1,300	1,200	17.5	21,000	17.30
Sugarbeets	2005	Michigan	D80 Southeast	2,900	2,600	19.0	55,000	16.20
Sugarbeets	**2005**	**Michigan**	**State Total**	**154,000**	**152,000**	**21.3**	**3,238,000**	**16.90**
Sugarbeets	2005	Minnesota	Becker	10,700	10,000	20.4	203,600	15.20
Sugarbeets	2005	Minnesota	Clay	57,000	56,100	19.8	1,113,000	17.50
Sugarbeets	2005	Minnesota	Kittson	36,600	18,300	11.8	216,300	15.50
Sugarbeets	2005	Minnesota	Mahnomen	5,600	5,600	22.5	125,900	15.10
Sugarbeets	2005	Minnesota	Marshall	47,400	42,600	15.4	659,500	15.10
Sugarbeets	2005	Minnesota	Norman	43,200	42,700	21.2	905,500	17.70
Sugarbeets	2005	Minnesota	Polk	99,100	97,900	20.2	1,974,400	17.80
Sugarbeets	2005	Minnesota	Red Lake	1,200	1,100	18.5	20,300	17.70
Sugarbeets	2005	Minnesota	D10 Combined Counties	400	400	18.5	7,400	17.80
Sugarbeets	2005	Minnesota	D10 Northwest	301,400	275,000	19.0	5,225,500	17.80
Sugarbeets	2005	Minnesota	Chippewa	54,300	34,200	25.0	855,000	15.80
Sugarbeets	2005	Minnesota	Grant	10,200	10,000	14.5	145,200	16.10
Sugarbeets	2005	Minnesota	Otter Tail	3,200	3,100	15.3	48,000	15.90
Sugarbeets	2005	Minnesota	Pope	2,300	2,200	24.7	54,300	16.40
Sugarbeets	2005	Minnesota	Stevens	3,900	3,800	23.5	89,400	16.20
Sugarbeets	2005	Minnesota	Swift	6,100	5,900	25.6	151,100	15.10
Sugarbeets	2005	Minnesota	Traverse	5,800	8,100	14.1	114,500	16.40
Sugarbeets	2005	Minnesota	Wilkin	47,100	45,400	18.3	828,700	16.60
Sugarbeets	2005	Minnesota	Yellow Medicine	2,800	2,700	27.9	75,200	16.00
Sugarbeets	2005	Minnesota	D40 Combined Counties	900	200	25.4	21,100	20.50
Sugarbeets	2005	Minnesota	D40 West Central	119,600	115,200	20.6	2,364,400	16.20
Sugarbeets	2005	Minnesota	Kandiyohi	13,200	13,100	26.3	345,000	15.60
Sugarbeets	2005	Minnesota	McLeod	1,500	1,400	23.0	32,200	15.50
Sugarbeets	2005	Minnesota	Meeker	1,900	1,800	24.8	44,700	15.60
Sugarbeets	2005	Minnesota	Renville	42,100	41,600	25.8	1,074,500	15.40
Sugarbeets	2005	Minnesota	Sibley	3,700	3,600	24.9	89,600	15.00
Sugarbeets	2005	Minnesota	Stearns	2,700	2,600	23.7	61,800	16.00
Sugarbeets	2005	Minnesota	D50 Central	65,100	64,100	25.7	1,647,600	15.50
Sugarbeets	2005	Minnesota	Redwood	3,400	3,300	27.3	90,100	15.40
Sugarbeets	2005	Minnesota	D70 Combined Counties	800	800	24.6	19,700	24.70
Sugarbeets	2005	Minnesota	D70 Southwest	4,200	4,100	26.8	109,600	15.80
Sugarbeets	2005	Minnesota	D99 Combined Districts	700	600	27.8	16,700	15.70
Sugarbeets	**2005**	**Minnesota**	**State Total**	**491,000**	**460,000**	**20.4**	**9,384,000**	**17.00**
Sugarbeets	2005	Montana	Dawson	2,900	2,230	20.7	46,200	15.01
Sugarbeets	2005	Montana	Richland	17,720	16,190	21.3	344,000	16.58
Sugarbeets	2005	Montana	Roosevelt	2,140	2,100	19.9	41,700	19.27
Sugarbeets	2005	Montana	D30 Northeast	22,860	20,520	21.0	431,900	16.56
Sugarbeets	2005	Montana	Big Horn	9,260	8,760	26.0	227,600	16.44
Sugarbeets	2005	Montana	Carbon	4,380	4,120	22.7	93,700	16.82
Sugarbeets	2005	Montana	Treasure	3,210	2,990	26.1	78,000	16.53
Sugarbeets	2005	Montana	Yellowstone	5,610	8,460	24.3	205,000	16.56
Sugarbeets	2005	Montana	D80 Combined Counties	200	200	30.0	6,000	16.43
Sugarbeets	2005	Montana	D80 South Central	25,580	24,580	24.9	611,300	16.56
Sugarbeets	2005	Montana	Custer	1,390	1,370	18.3	25,400	16.54

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Idaho	D20 South Central	107,500	107,000	26.0	2,780,000	17.70
Sugarbeets	2005	Idaho	Bingham	19,200	18,200	29.8	541,000	17.60
Sugarbeets	2005	Idaho	Power	13,300	13,200	30.7	405,000	17.50
Sugarbeets	2005	Idaho	D60 East	32,500	32,000	29.6	946,000	17.65
Sugarbeets	**2005**	**Idaho**	**State Total**	**169,000**	**167,000**	**27.1**	**4,526,000**	**17.57**
Sugarbeets	2005	Michigan	D30 Combined Counties	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	D30 Northeast	600	600	21.7	13,000	17.10
Sugarbeets	2005	Michigan	Glazwin	1,000	1,000	23.0	23,000	17.20
Sugarbeets	2005	Michigan	Gratiot	11,000	10,800	20.4	220,000	17.10
Sugarbeets	2005	Michigan	Isabella	900	900	20.0	18,000	16.80
Sugarbeets	2005	Michigan	Midland	3,200	3,200	19.7	63,000	16.20
Sugarbeets	2005	Michigan	Montcalm	1,100	1,100	22.7	25,000	16.70
Sugarbeets	2005	Michigan	D60 Central	17,200	17,000	20.5	348,000	16.80
Sugarbeets	2005	Michigan	Arenac	3,700	3,700	23.5	87,000	17.20
Sugarbeets	2005	Michigan	Bay	14,500	14,000	19.1	268,000	16.50
Sugarbeets	2005	Michigan	Huron	54,500	54,000	22.6	1,220,000	17.10
Sugarbeets	2005	Michigan	Saginaw	16,300	16,200	20.1	326,000	16.80
Sugarbeets	2005	Michigan	Sanilac	20,000	19,800	22.0	436,000	16.80
Sugarbeets	2005	Michigan	Tuscola	21,000	20,600	20.5	423,000	16.90
Sugarbeets	2005	Michigan	D80 East Central	132,000	125,300	21.5	2,700,000	16.90
Sugarbeets	2005	Michigan	Clinton	1,800	1,800	19.4	35,000	17.50
Sugarbeets	2005	Michigan	Ionia	500	500	18.0	9,000	17.90
Sugarbeets	2005	Michigan	Shiawassee	1,000	900	20.0	18,000	17.30
Sugarbeets	2005	Michigan	D90 South Central	3,300	3,200	19.1	61,000	17.50
Sugarbeets	2005	Michigan	Genesee	700	700	20.0	14,000	13.40
Sugarbeets	2005	Michigan	Lapeer	1,000	1,000	20.0	20,000	17.00
Sugarbeets	2005	Michigan	St. Clair	1,200	1,200	17.5	21,000	17.30
Sugarbeets	2005	Michigan	D90 Southeast	2,900	2,900	19.0	55,000	16.20
Sugarbeets	**2005**	**Michigan**	**State Total**	**154,000**	**152,000**	**21.3**	**3,238,000**	**16.90**
Sugarbeets	2005	Minnesota	Becker	10,700	10,000	20.4	203,600	15.20
Sugarbeets	2005	Minnesota	Clay	57,000	56,100	19.8	1,113,000	17.50
Sugarbeets	2005	Minnesota	Kittson	36,600	18,300	11.8	215,300	15.50
Sugarbeets	2005	Minnesota	Mahnomen	5,600	5,600	22.5	125,900	15.10
Sugarbeets	2005	Minnesota	Marshall	47,400	42,900	15.4	658,500	15.10
Sugarbeets	2005	Minnesota	Norman	43,200	42,700	21.2	905,500	17.70
Sugarbeets	2005	Minnesota	Polk	99,100	97,900	20.3	1,974,400	17.80
Sugarbeets	2005	Minnesota	Red Lake	1,200	1,100	18.5	20,300	17.70
Sugarbeets	2005	Minnesota	D10 Combined Counties	400	400	18.5	7,400	17.80
Sugarbeets	2005	Minnesota	D10 Northwest	301,400	275,000	19.0	5,225,500	17.80
Sugarbeets	2005	Minnesota	Chippewa	34,300	34,200	25.0	852,000	15.80
Sugarbeets	2005	Minnesota	Grant	10,200	10,000	14.5	145,200	16.10
Sugarbeets	2005	Minnesota	Otter Tail	3,200	3,100	15.8	48,900	15.90
Sugarbeets	2005	Minnesota	Pope	2,300	2,200	24.7	54,300	16.40
Sugarbeets	2005	Minnesota	Stevens	3,900	3,800	23.5	89,400	16.20
Sugarbeets	2005	Minnesota	Swift	6,100	5,900	25.6	151,100	16.10
Sugarbeets	2005	Minnesota	Traverse	6,800	8,100	14.1	114,600	16.40
Sugarbeets	2005	Minnesota	Wilkin	47,100	45,400	18.3	828,700	16.80
Sugarbeets	2005	Minnesota	Yellow Medicine	2,800	2,700	27.9	75,200	16.00
Sugarbeets	2005	Minnesota	D40 Combined Counties	900	800	26.4	21,100	20.50
Sugarbeets	2005	Minnesota	D40 West Central	119,600	116,200	20.6	2,394,400	16.20
Sugarbeets	2005	Minnesota	Kandiyohi	13,200	13,100	26.3	345,000	15.90
Sugarbeets	2005	Minnesota	McLeod	1,500	1,400	23.6	32,200	15.50
Sugarbeets	2005	Minnesota	Meeker	1,900	1,800	24.8	44,700	15.80
Sugarbeets	2005	Minnesota	Renville	42,100	41,000	25.8	1,074,500	15.40
Sugarbeets	2005	Minnesota	Sibley	3,700	3,600	24.9	89,600	15.00
Sugarbeets	2005	Minnesota	Stearns	2,700	2,600	23.7	61,600	16.00
Sugarbeets	2005	Minnesota	D50 Central	65,100	64,100	25.7	1,647,600	15.50
Sugarbeets	2005	Minnesota	Redwood	3,400	3,300	27.3	90,100	15.40
Sugarbeets	2005	Minnesota	D70 Combined Counties	800	800	24.6	19,700	24.70
Sugarbeets	2005	Minnesota	D70 Southwest	4,200	4,100	26.8	109,500	15.50
Sugarbeets	2005	Minnesota	D99 Combined Districts	700	600	27.8	16,750	15.70
Sugarbeets	**2005**	**Minnesota**	**State Total**	**491,000**	**460,000**	**20.4**	**9,384,000**	**17.00**
Sugarbeets	2005	Montana	Dawson	2,990	2,230	20.7	46,200	15.01
Sugarbeets	2005	Montana	Richland	17,720	16,190	21.2	344,000	15.50
Sugarbeets	2005	Montana	Roosevelt	2,140	2,100	19.9	41,700	16.27
Sugarbeets	2005	Montana	D20 Northeast	22,850	20,520	21.0	431,900	15.59
Sugarbeets	2005	Montana	Big Horn	9,260	8,790	25.9	227,600	16.44
Sugarbeets	2005	Montana	Carbon	4,280	4,120	22.7	93,700	16.82
Sugarbeets	2005	Montana	Treasure	3,210	2,990	26.1	78,000	16.53
Sugarbeets	2005	Montana	Yellowstone	8,610	8,460	24.3	205,000	16.59
Sugarbeets	2005	Montana	D30 Combined Counties	200	200	30.0	6,000	16.43
Sugarbeets	2005	Montana	D80 South Central	25,560	24,560	24.9	611,300	15.56
Sugarbeets	2005	Montana	Custer	1,390	1,370	19.3	26,400	15.54

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Montana	Prairie	1,770	1,630	15.2	23,300	15.34
Sugarbeets	2005	Montana	Rosebud	2,330	1,920	28.1	53,100	16.66
Sugarbeets	2005	Montana	D90 Southeast	5,490	4,820	20.7	99,800	17.55
Sugarbeets	**2005**	**Montana**	**State Total**	**53,900**	**49,900**	**22.9**	**1,143,000**	**17.41**
Sugarbeets	2005	Nebraska	Banner	600	800	16.9	13,500	16.70
Sugarbeets	2005	Nebraska	Box Butte	21,100	20,200	19.3	390,400	16.70
Sugarbeets	2005	Nebraska	Cheyenne	2,800	2,800	18.6	52,100	17.40
Sugarbeets	2005	Nebraska	Deuel	500	500	18.4	9,200	15.60
Sugarbeets	2005	Nebraska	Kimball	2,600	2,500	22.6	56,900	17.20
Sugarbeets	2005	Nebraska	Morrill	4,300	3,600	19.9	71,700	15.40
Sugarbeets	2005	Nebraska	Scotts Bluff	7,500	6,700	22.0	147,100	15.90
Sugarbeets	2005	Nebraska	Sheridan	2,400	2,400	23.1	55,400	16.80
Sugarbeets	2005	Nebraska	D10 Combined Counties	600	500	21.4	10,700	16.10
Sugarbeets	2005	Nebraska	D10 Northwest	42,500	40,000	20.2	595,000	16.50
Sugarbeets	2005	Nebraska	Chase	3,400	3,000	23.6	70,800	15.40
Sugarbeets	2005	Nebraska	Keith	1,100	1,000	23.5	23,500	16.50
Sugarbeets	2005	Nebraska	Perkins	1,400	1,300	18.2	23,700	15.10
Sugarbeets	2005	Nebraska	D70 Southwest	5,900	5,300	22.3	118,000	15.80
Sugarbeets	**2005**	**Nebraska**	**State Total**	**48,400**	**45,300**	**20.4**	**924,000**	**16.40**
Sugarbeets	2005	North Dakota	Williams	5,000	4,900	20.0	98,000	19.14
Sugarbeets	2005	North Dakota	D10 Northwest	5,000	4,900	20.0	98,000	19.14
Sugarbeets	2005	North Dakota	Cavalier	100	100	15.0	1,500	17.12
Sugarbeets	2005	North Dakota	Grand Forks	31,300	30,500	20.4	621,000	15.03
Sugarbeets	2005	North Dakota	Pembina	78,200	74,700	15.7	1,174,500	15.22
Sugarbeets	2005	North Dakota	Walsh	43,100	42,000	20.1	844,000	15.40
Sugarbeets	2005	North Dakota	D30 Northeast	153,700	147,300	17.9	2,641,000	15.23
Sugarbeets	2005	North Dakota	McKenzie	10,700	10,600	22.3	236,000	15.98
Sugarbeets	2005	North Dakota	D40 West Central	10,700	10,600	22.3	236,000	15.98
Sugarbeets	2005	North Dakota	Cass	24,500	23,000	20.9	482,000	15.00
Sugarbeets	2005	North Dakota	Steele	100	100	20.0	2,000	15.10
Sugarbeets	2005	North Dakota	Traill	29,100	28,400	20.9	593,000	17.81
Sugarbeets	2005	North Dakota	D60 East Central	53,700	51,500	20.9	1,075,000	17.90
Sugarbeets	2005	North Dakota	Richland	31,900	28,700	18.0	516,000	16.41
Sugarbeets	2005	North Dakota	D90 Southeast	31,900	28,700	18.0	516,000	16.41
Sugarbeets	**2005**	**North Dakota**	**State Total**	**255,000**	**243,000**	**18.8**	**4,568,000**	**18.00**
Sugarbeets	2005	Oregon	Union	2,000	2,000	25.8	51,500	15.30
Sugarbeets	2005	Oregon	D30 Northeast	2,000	2,000	25.8	51,500	15.30
Sugarbeets	2005	Oregon	Malheur	7,600	7,700	33.7	259,500	16.31
Sugarbeets	2005	Oregon	D80 Southeast	7,600	7,700	33.7	259,500	16.31
Sugarbeets	**2005**	**Oregon**	**State Total**	**9,800**	**9,700**	**32.1**	**311,000**	**16.71**
Sugarbeets	2005	Washington	Benton	1,700	1,700	40.6	69,000	16.75
Sugarbeets	2005	Washington	D20 Central	1,700	1,700	40.6	69,000	16.75
Sugarbeets	**2005**	**Washington**	**State Total**	**1,700**	**1,700**	**40.6**	**69,000**	**16.75**
Sugarbeets	2005	Wyoming	Big Horn	8,200	8,200	22.3	183,200	17.66
Sugarbeets	2005	Wyoming	Fremont	3,100	3,100	22.8	70,800	17.09
Sugarbeets	2005	Wyoming	Park	12,300	12,100	22.2	269,000	17.79
Sugarbeets	2005	Wyoming	Washakie	8,600	8,600	23.9	205,500	17.27
Sugarbeets	2005	Wyoming	D10 Northwest	32,200	32,000	22.8	728,500	17.63
Sugarbeets	2005	Wyoming	Goshen	1,200	1,200	16.0	19,200	16.23
Sugarbeets	2005	Wyoming	Laramie	700	600	20.5	12,300	17.23
Sugarbeets	2005	Wyoming	Platte	2,100	2,100	19.5	41,000	17.33
Sugarbeets	2005	Wyoming	D50 Southeast	4,000	3,900	18.6	72,500	17.01
Sugarbeets	**2005**	**Wyoming**	**State Total**	**36,200**	**35,900**	**22.3**	**801,000**	**17.57**

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Montana	Prairie	1,770	1,530	15.2	23,300	15.34
Sugarbeets	2005	Montana	Rosebud	2,350	1,920	26.1	50,100	15.66
Sugarbeets	2005	Montana	D90 Southeast	5,480	4,820	20.7	99,800	17.66
Sugarbeets	**2005**	**Montana**	**State Total**	**53,900**	**49,900**	**22.9**	**1,143,000**	**17.41**
Sugarbeets	2005	Nebraska	Banner	800	800	16.9	13,500	16.70
Sugarbeets	2005	Nebraska	Box Butte	21,100	20,300	19.3	390,400	16.70
Sugarbeets	2005	Nebraska	Cheyenne	2,800	2,200	18.6	50,100	17.40
Sugarbeets	2005	Nebraska	Deuel	500	500	18.4	9,200	15.60
Sugarbeets	2005	Nebraska	Kimball	3,500	3,300	22.4	55,900	17.20
Sugarbeets	2005	Nebraska	Morrill	4,300	3,800	19.9	71,700	15.40
Sugarbeets	2005	Nebraska	Scotts Bluff	7,500	6,700	22.0	147,100	15.90
Sugarbeets	2005	Nebraska	Sheridan	2,400	2,400	23.1	55,400	16.60
Sugarbeets	2005	Nebraska	D10 Combined Counties	600	500	21.4	10,700	16.10
Sugarbeets	2005	Nebraska	D10 Northwest	42,500	40,000	20.2	806,000	16.60
Sugarbeets	2005	Nebraska	Chase	3,400	3,000	23.6	70,600	15.40
Sugarbeets	2005	Nebraska	Keith	1,100	1,000	23.5	23,500	16.60
Sugarbeets	2005	Nebraska	Perkins	1,400	1,300	18.2	23,700	16.10
Sugarbeets	2005	Nebraska	D70 Southwest	5,900	5,300	22.3	118,000	15.60
Sugarbeets	**2005**	**Nebraska**	**State Total**	**48,400**	**45,300**	**20.4**	**924,000**	**16.40**
Sugarbeets	2005	North Dakota	Williams	5,000	4,900	20.0	98,000	19.14
Sugarbeets	2005	North Dakota	D10 Northwest	5,000	4,900	20.0	98,000	19.14
Sugarbeets	2005	North Dakota	Cavalier	100	100	15.0	1,500	17.12
Sugarbeets	2005	North Dakota	Grand Forks	31,300	30,500	20.4	621,000	15.03
Sugarbeets	2005	North Dakota	Pembina	79,200	74,700	15.7	1,174,500	15.22
Sugarbeets	2005	North Dakota	Walsh	43,100	42,000	20.1	844,000	15.40
Sugarbeets	2005	North Dakota	D30 Northeast	153,700	147,300	17.9	2,641,000	15.25
Sugarbeets	2005	North Dakota	McKenzie	10,700	10,600	22.3	236,000	15.86
Sugarbeets	2005	North Dakota	D40 West Central	10,700	10,600	22.3	236,000	15.86
Sugarbeets	2005	North Dakota	Cass	24,500	23,000	20.9	480,000	15.00
Sugarbeets	2005	North Dakota	Steele	100	100	20.0	2,000	15.10
Sugarbeets	2005	North Dakota	Traill	29,100	26,400	20.9	599,000	17.81
Sugarbeets	2005	North Dakota	D60 East Central	53,700	51,500	20.9	1,075,000	17.90
Sugarbeets	2005	North Dakota	Richland	31,900	26,700	15.0	518,000	16.41
Sugarbeets	2005	North Dakota	D90 Southeast	31,900	28,700	18.0	515,000	16.41
Sugarbeets	**2005**	**North Dakota**	**State Total**	**255,000**	**243,000**	**18.8**	**4,568,000**	**18.00**
Sugarbeets	2005	Oregon	Union	2,000	2,000	25.8	51,600	15.30
Sugarbeets	2005	Oregon	D30 Northeast	2,000	2,000	25.8	51,600	15.30
Sugarbeets	2005	Oregon	Malheur	7,800	7,700	33.7	259,500	16.31
Sugarbeets	2005	Oregon	D80 Southeast	7,800	7,700	33.7	259,500	16.31
Sugarbeets	**2005**	**Oregon**	**State Total**	**9,800**	**9,700**	**32.1**	**311,000**	**16.71**
Sugarbeets	2005	Washington	Benton	1,700	1,700	40.6	69,000	16.75
Sugarbeets	2005	Washington	D20 Central	1,700	1,700	40.6	69,000	16.75
Sugarbeets	**2005**	**Washington**	**State Total**	**1,700**	**1,700**	**40.6**	**69,000**	**16.75**
Sugarbeets	2005	Wyoming	Big Horn	6,200	6,200	22.3	153,200	17.66
Sugarbeets	2005	Wyoming	Fremont	3,100	3,100	22.8	70,800	17.90
Sugarbeets	2005	Wyoming	Park	12,300	12,100	22.2	269,000	17.79
Sugarbeets	2005	Wyoming	Washakie	8,600	8,600	23.9	205,500	17.27
Sugarbeets	2005	Wyoming	D10 Northwest	32,200	32,000	22.8	728,500	17.83
Sugarbeets	2005	Wyoming	Goshen	1,200	1,200	16.0	19,200	15.23
Sugarbeets	2005	Wyoming	Laramie	700	600	20.5	12,300	17.22
Sugarbeets	2005	Wyoming	Platte	2,100	2,100	19.5	41,000	17.35
Sugarbeets	2005	Wyoming	D50 Southeast	4,000	3,900	18.6	72,500	17.01
Sugarbeets	**2005**	**Wyoming**	**State Total**	**36,200**	**35,900**	**22.3**	**801,000**	**17.57**

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Montana	Prairie	1,770	1,630	16.2	23,305	15.34
Sugarbeets	2005	Montana	Rosebud	2,330	1,920	26.1	50,100	15.66
Sugarbeets	2005	Montana	D90 Southeast	5,490	4,820	20.7	99,800	17.55
Sugarbeets	**2005**	**Montana**	**State Total**	**53,900**	**49,900**	**22.9**	**1,143,000**	**17.41**
Sugarbeets	2005	Nebraska	Banner	800	800	16.9	13,500	16.70
Sugarbeets	2005	Nebraska	Box Butte	21,100	20,200	19.3	390,400	16.70
Sugarbeets	2005	Nebraska	Cheyenne	2,800	3,200	16.6	52,100	17.40
Sugarbeets	2005	Nebraska	Deuel	500	500	18.4	9,200	16.60
Sugarbeets	2005	Nebraska	Kimball	2,500	3,500	22.5	55,900	17.20
Sugarbeets	2005	Nebraska	Morrill	4,300	3,600	19.9	71,700	15.40
Sugarbeets	2005	Nebraska	Scotts Bluff	7,500	6,700	22.0	147,100	15.90
Sugarbeets	2005	Nebraska	Sheridan	2,400	2,400	23.1	55,400	16.60
Sugarbeets	2005	Nebraska	D10 Combined Counties	600	500	21.4	10,700	16.10
Sugarbeets	2005	Nebraska	D10 Northwest	42,500	40,000	20.2	808,000	16.50
Sugarbeets	2005	Nebraska	Chase	3,400	3,000	23.6	70,800	15.40
Sugarbeets	2005	Nebraska	Keith	1,100	1,000	23.5	23,500	16.50
Sugarbeets	2005	Nebraska	Perkins	1,400	1,300	18.2	23,700	16.10
Sugarbeets	2005	Nebraska	D70 Southwest	5,900	5,300	22.3	118,000	15.80
Sugarbeets	**2005**	**Nebraska**	**State Total**	**48,400**	**45,300**	**20.4**	**924,000**	**16.40**
Sugarbeets	2005	North Dakota	Williams	5,000	4,900	20.0	98,000	19.14
Sugarbeets	2005	North Dakota	D10 Northwest	5,000	4,900	20.0	98,000	19.14
Sugarbeets	2005	North Dakota	Cavalier	100	100	15.0	1,500	17.12
Sugarbeets	2005	North Dakota	Grand Forks	31,300	30,500	20.4	621,000	16.03
Sugarbeets	2005	North Dakota	Pembina	79,200	74,700	15.7	1,174,500	15.22
Sugarbeets	2005	North Dakota	Walsh	43,100	42,000	20.1	844,000	15.40
Sugarbeets	2005	North Dakota	D30 Northeast	153,700	147,300	17.9	2,641,000	15.23
Sugarbeets	2005	North Dakota	McKenzie	10,700	10,600	22.3	236,000	15.98
Sugarbeets	2005	North Dakota	D40 West Central	10,700	10,600	22.3	236,000	15.98
Sugarbeets	2005	North Dakota	Cass	24,600	23,000	20.9	480,000	16.00
Sugarbeets	2005	North Dakota	Steele	100	100	20.0	2,000	15.10
Sugarbeets	2005	North Dakota	Traill	29,100	28,400	20.9	593,000	17.61
Sugarbeets	2005	North Dakota	D60 East Central	53,700	51,500	20.9	1,075,000	17.90
Sugarbeets	2005	North Dakota	Richland	31,900	28,700	18.0	518,000	16.41
Sugarbeets	2005	North Dakota	D90 Southeast	31,900	28,700	18.0	518,000	16.41
Sugarbeets	**2005**	**North Dakota**	**State Total**	**255,000**	**243,000**	**18.8**	**4,568,000**	**18.00**
Sugarbeets	2005	Oregon	Union	2,000	2,000	25.8	51,600	15.30
Sugarbeets	2005	Oregon	D30 Northeast	2,000	2,000	25.8	51,600	15.30
Sugarbeets	2005	Oregon	Malheur	7,800	7,700	33.7	259,500	16.31
Sugarbeets	2005	Oregon	D80 Southeast	7,800	7,700	33.7	259,500	16.31
Sugarbeets	**2005**	**Oregon**	**State Total**	**9,800**	**9,700**	**32.1**	**311,000**	**16.71**
Sugarbeets	2005	Washington	Benton	1,700	1,700	40.6	69,000	16.75
Sugarbeets	2005	Washington	D20 Central	1,700	1,700	40.6	69,000	16.75
Sugarbeets	**2005**	**Washington**	**State Total**	**1,700**	**1,700**	**40.6**	**69,000**	**16.75**
Sugarbeets	2005	Wyoming	Big Horn	8,200	8,200	22.3	183,200	17.66
Sugarbeets	2005	Wyoming	Fremont	3,100	3,100	22.8	70,600	17.99
Sugarbeets	2005	Wyoming	Park	12,300	12,100	22.2	269,000	17.79
Sugarbeets	2005	Wyoming	Washakie	9,600	9,000	23.0	205,500	17.27
Sugarbeets	2005	Wyoming	D10 Northwest	32,200	32,000	22.8	729,500	17.83
Sugarbeets	2005	Wyoming	Goshen	1,200	1,200	16.0	19,200	16.23
Sugarbeets	2005	Wyoming	Laramie	700	600	20.5	12,300	17.22
Sugarbeets	2005	Wyoming	Platte	2,100	2,100	19.5	41,000	17.32
Sugarbeets	2005	Wyoming	D50 Southeast	4,000	3,900	18.6	72,500	17.01
Sugarbeets	**2005**	**Wyoming**	**State Total**	**36,200**	**35,900**	**22.3**	**801,000**	**17.57**

Commodity	Year	State	County	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Sucrose (Percent)
Sugarbeets	2005	Montana	Prairie	1,770	1,630	16.2	23,300	16.34
Sugarbeets	2005	Montana	Rosebud	2,330	1,930	26.1	53,100	16.66
Sugarbeets	2005	Montana	D90 Southeast	5,490	4,220	20.7	99,800	17.55
Sugarbeets	**2005**	**Montana**	**State Total**	**53,900**	**49,900**	**22.9**	**1,143,000**	**17.41**
Sugarbeets	2005	Nebraska	Banner	800	800	16.9	13,500	16.70
Sugarbeets	2005	Nebraska	Box Butte	21,100	20,200	19.3	390,400	16.70
Sugarbeets	2005	Nebraska	Cheyenne	2,800	2,800	18.6	52,100	17.40
Sugarbeets	2005	Nebraska	Deuel	500	500	16.4	8,200	15.60
Sugarbeets	2005	Nebraska	Kimball	3,500	3,500	22.4	55,900	17.20
Sugarbeets	2005	Nebraska	Morrill	4,300	3,600	19.9	71,700	15.40
Sugarbeets	2005	Nebraska	Scotts Bluff	7,500	6,700	22.0	147,100	15.90
Sugarbeets	2005	Nebraska	Sheridan	2,400	2,400	23.1	55,400	16.80
Sugarbeets	2005	Nebraska	D10 Combined Counties	600	500	21.4	10,700	16.10
Sugarbeets	2005	Nebraska	D10 Northwest	42,500	40,000	20.2	808,000	16.50
Sugarbeets	2005	Nebraska	Chase	3,400	3,000	23.6	70,800	15.40
Sugarbeets	2005	Nebraska	Keith	1,100	1,000	23.5	23,500	16.50
Sugarbeets	2005	Nebraska	Perkins	1,400	1,300	18.2	23,705	15.10
Sugarbeets	2005	Nebraska	D70 Southwest	5,900	5,300	22.3	118,000	15.60
Sugarbeets	**2005**	**Nebraska**	**State Total**	**48,400**	**45,300**	**20.4**	**924,000**	**16.40**
Sugarbeets	2005	North Dakota	Williams	5,000	4,900	20.0	98,000	18.14
Sugarbeets	2005	North Dakota	D10 Northwest	5,000	4,900	20.0	98,000	18.14
Sugarbeets	2005	North Dakota	Cavalier	100	100	15.0	1,500	17.12
Sugarbeets	2005	North Dakota	Grand Forks	31,900	30,500	20.4	621,000	16.03
Sugarbeets	2005	North Dakota	Pembina	79,200	74,700	15.7	1,174,500	16.22
Sugarbeets	2005	North Dakota	Walsh	43,100	42,000	20.1	844,000	16.40
Sugarbeets	2005	North Dakota	D30 Northeast	152,700	147,300	17.9	2,641,000	16.23
Sugarbeets	2005	North Dakota	McKenzie	10,700	10,600	22.3	236,000	15.98
Sugarbeets	2005	North Dakota	D40 West Central	10,700	10,600	22.3	236,000	15.98
Sugarbeets	2005	North Dakota	Cass	24,500	23,000	20.9	480,000	15.00
Sugarbeets	2005	North Dakota	Steele	100	100	20.0	2,000	16.10
Sugarbeets	2005	North Dakota	Traill	29,100	28,400	20.9	593,000	17.81
Sugarbeets	2005	North Dakota	D60 East Central	53,700	51,300	20.9	1,075,000	17.90
Sugarbeets	2005	North Dakota	Richland	31,900	28,700	18.0	518,000	16.41
Sugarbeets	2005	North Dakota	D90 Southeast	31,900	28,700	18.0	518,000	16.41
Sugarbeets	**2005**	**North Dakota**	**State Total**	**255,000**	**243,000**	**18.8**	**4,568,000**	**16.00**
Sugarbeets	2005	Oregon	Union	2,000	2,000	25.8	51,500	15.30
Sugarbeets	2005	Oregon	D30 Northeast	2,000	2,000	25.8	51,500	15.30
Sugarbeets	2005	Oregon	Malheur	7,800	7,700	33.7	259,500	16.31
Sugarbeets	2005	Oregon	D80 Southeast	7,800	7,700	33.7	259,500	16.31
Sugarbeets	**2005**	**Oregon**	**State Total**	**9,800**	**9,700**	**32.1**	**311,000**	**16.71**
Sugarbeets	2005	Washington	Benton	1,700	1,700	40.6	69,000	16.75
Sugarbeets	2005	Washington	D20 Central	1,700	1,700	40.6	69,000	16.75
Sugarbeets	**2005**	**Washington**	**State Total**	**1,700**	**1,700**	**40.6**	**69,000**	**16.75**
Sugarbeets	2005	Wyoming	Big Horn	8,200	8,200	22.3	183,200	17.66
Sugarbeets	2005	Wyoming	Fremont	3,100	3,100	22.8	70,800	17.99
Sugarbeets	2005	Wyoming	Park	12,300	12,100	22.2	269,000	17.79
Sugarbeets	2005	Wyoming	Washakie	9,600	8,600	23.9	205,500	17.27
Sugarbeets	2005	Wyoming	D10 Northwest	32,200	32,000	22.6	726,500	17.63
Sugarbeets	2005	Wyoming	Goshen	1,200	1,200	16.0	19,200	16.23
Sugarbeets	2005	Wyoming	Laramie	700	600	20.5	12,300	17.22
Sugarbeets	2005	Wyoming	Platte	2,100	2,100	19.5	41,000	17.32
Sugarbeets	2005	Wyoming	D50 Southeast	4,000	3,900	18.6	72,500	17.01
Sugarbeets	**2005**	**Wyoming**	**State Total**	**36,200**	**35,900**	**22.3**	**801,000**	**17.57**

Commodity	Year	State	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Price per Unit (Dollars per Ton)	Value of production (Thousands of Dollars)
Sugarbeets	2010	California	25					
Sugarbeets	2010	Colorado	30					
Sugarbeets	2010	Idaho	189					
Sugarbeets	2010	Michigan	147					
Sugarbeets	2010	Minnesota	446					
Sugarbeets	2010	Montana	42					
Sugarbeets	2010	Nebraska	46					
Sugarbeets	2010	North Dakota	227					
Sugarbeets	2010	Oregon	11					
Sugarbeets	2010	United States	1,174					
Sugarbeets	2010	Wyoming	33					
Sugarbeets	2009	California	25	25	35.00	885		
Sugarbeets	2009	Colorado	35	35	27.50	963		
Sugarbeets	2009	Idaho	164	163	34.30	5,591		
Sugarbeets	2009	Michigan	138	136	24.40	3,315		
Sugarbeets	2009	Minnesota	464	449	23.70	10,641		
Sugarbeets	2009	Montana	38	34	29.80	1,001		
Sugarbeets	2009	Nebraska	53	53	24.60	1,294		
Sugarbeets	2009	North Dakota	223	215	22.00	4,795		
Sugarbeets	2009	Oregon	11	11	37.60	395		
Sugarbeets	2009	United States	1,186	1,149	25.70	29,563		
Sugarbeets	2009	Wyoming	32	26	26.30	675		
Sugarbeets	2008	California	26	25	41.60	1,052	$44.80	$47,130
Sugarbeets	2008	Colorado	34	29	26.50	766	$47.80	$36,232
Sugarbeets	2008	Idaho	131	116	31.20	3,619	$42.00	$151,995
Sugarbeets	2008	Michigan	137	136	25.70	3,903	$44.00	$171,732
Sugarbeets	2008	Minnesota	440	399	24.70	9,855	$49.90	$491,765
Sugarbeets	2008	Montana	32	31	26.80	823	$50.80	$41,808
Sugarbeets	2008	Nebraska	45	37	22.60	843	$50.80	$42,824
Sugarbeets	2008	North Dakota	203	197	25.90	5,102	$51.00	$260,202
Sugarbeets	2008	Oregon	7	6	33.10	195	$42.00	$8,190
Sugarbeets	2008	United States	1,091	1,005	26.60	26,881	$48.00	$1,289,821
Sugarbeets	2008	Washington	2	2	41.90	67	$42.00	$2,814
Sugarbeets	2008	Wyoming	30	27	24.60	664	$52.60	$34,926
Sugarbeets	2007	California	40	39	35.50	1,385	$45.60	$60,517
Sugarbeets	2007	Colorado	33	29	26.20	765	$36.00	$27,540
Sugarbeets	2007	Idaho	169	167	34.40	5,745	$36.90	$211,991
Sugarbeets	2007	Michigan	150	149	23.40	3,487	$36.00	$125,532
Sugarbeets	2007	Minnesota	486	451	23.80	11,445	$45.20	$517,460
Sugarbeets	2007	Montana	48	47	24.70	1,161	$39.10	$45,395
Sugarbeets	2007	Nebraska	48	44	23.60	1,041	$40.40	$42,056
Sugarbeets	2007	North Dakota	252	247	23.10	5,705	$46.30	$264,185
Sugarbeets	2007	Oregon	12	11	31.90	351	$36.90	$12,962
Sugarbeets	2007	United States	1,269	1,247	25.50	31,834	$42.00	$1,337,175
Sugarbeets	2007	Washington	2	2	42.00	84	$36.90	$3,100
Sugarbeets	2007	Wyoming	31	30	21.80	655	$40.20	$26,452
Sugarbeets	2006	California	43	43	36.10	1,556	$42.20	$65,653
Sugarbeets	2006	Colorado	42	38	23.40	889	$42.20	$37,516
Sugarbeets	2006	Idaho	168	167	31.70	5,625	$39.20	$234,155
Sugarbeets	2006	Michigan	156	154	23.20	3,573	$38.00	$135,774
Sugarbeets	2006	Minnesota	504	477	24.90	11,877	$46.70	$554,656
Sugarbeets	2006	Montana	54	49	27.00	1,310	$41.60	$54,496
Sugarbeets	2006	Nebraska	61	55	23.30	1,347	$44.50	$59,942
Sugarbeets	2006	North Dakota	261	243	26.00	6,315	$48.90	$305,950
Sugarbeets	2006	Oregon	13	13	30.10	394	$39.60	$15,593
Sugarbeets	2006	United States	1,366	1,304	26.10	34,064	$44.20	$1,506,065
Sugarbeets	2006	Washington	2	2	37.00	74	$39.60	$2,928
Sugarbeets	2006	Wyoming	43	40	19.90	795	$46.80	$37,348
Sugarbeets	2005	California	44	44	37.10	1,636	$41.80	$68,385
Sugarbeets	2005	Colorado	36	34	24.30	833	$40.70	$33,903
Sugarbeets	2005	Idaho	169	167	27.10	4,526	$44.40	$200,954
Sugarbeets	2005	Michigan	164	152	21.30	3,235	$34.40	$111,387
Sugarbeets	2005	Minnesota	491	460	20.40	9,384	$43.80	$411,019
Sugarbeets	2005	Montana	54	50	22.90	1,143	$45.30	$51,775
Sugarbeets	2005	Nebraska	48	45	20.40	924	$43.10	$39,824
Sugarbeets	2005	North Dakota	255	245	16.80	4,585	$49.20	$224,746
Sugarbeets	2005	Oregon	10	10	32.10	311	$44.40	$13,805
Sugarbeets	2005	United States	1,300	1,245	22.10	27,433	$43.50	$1,193,151
Sugarbeets	2005	Washington	2	2	40.60	69	$44.40	$3,064
Sugarbeets	2005	Wyoming	36	36	22.30	801	$42.20	$34,283

Commodity	Year	State	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Price per Unit (Dollars per Ton)	Value of production (Thousands of Dollars)
Sugarbeets	2012	California	25					
Sugarbeets	2012	Colorado	30					
Sugarbeets	2012	Idaho	182					
Sugarbeets	2012	Michigan	147					
Sugarbeets	2012	Minnesota	445					
Sugarbeets	2012	Montana	42					
Sugarbeets	2012	Nebraska	46					
Sugarbeets	2012	North Dakota	227					
Sugarbeets	2012	Oregon	11					
Sugarbeets	2012	United States	1,174					
Sugarbeets	2012	Wyoming	32					
Sugarbeets	2007	California	25	25	35.00	886		
Sugarbeets	2007	Colorado	36	35	27.50	963		
Sugarbeets	2007	Idaho	164	163	34.30	5,591		
Sugarbeets	2007	Michigan	138	136	24.40	3,315		
Sugarbeets	2007	Minnesota	464	449	23.70	10,641		
Sugarbeets	2007	Montana	38	34	29.80	1,001		
Sugarbeets	2007	Nebraska	53	53	24.60	1,294		
Sugarbeets	2007	North Dakota	225	216	22.00	4,766		
Sugarbeets	2007	Oregon	11	11	37.80	395		
Sugarbeets	2007	United States	1,186	1,149	25.70	29,583		
Sugarbeets	2007	Wyoming	32	26	26.50	678		
Sugarbeets	2006	California	26	25	41.80	1,052	$44.80	$47,130
Sugarbeets	2006	Colorado	34	29	26.50	765	$47.80	$36,232
Sugarbeets	2006	Idaho	131	116	31.20	3,619	$43.00	$151,995
Sugarbeets	2006	Michigan	137	136	25.70	3,903	$44.00	$171,732
Sugarbeets	2006	Minnesota	440	399	24.70	9,855	$49.90	$491,765
Sugarbeets	2006	Montana	32	31	26.80	833	$50.80	$41,805
Sugarbeets	2006	Nebraska	45	37	22.60	843	$50.80	$42,824
Sugarbeets	2006	North Dakota	203	197	25.90	5,102	$51.00	$260,202
Sugarbeets	2006	Oregon	7	6	33.10	195	$42.00	$5,190
Sugarbeets	2006	United States	1,091	1,006	26.80	26,881	$48.00	$1,289,821
Sugarbeets	2006	Washington	2	2	41.00	67	$42.00	$2,814
Sugarbeets	2006	Wyoming	30	27	24.50	664	$52.80	$34,925
Sugarbeets	2007	California	40	39	35.50	1,385	$43.60	$60,517
Sugarbeets	2007	Colorado	32	29	26.20	765	$36.00	$27,540
Sugarbeets	2007	Idaho	169	167	34.40	5,745	$36.90	$211,991
Sugarbeets	2007	Michigan	150	149	23.40	3,487	$36.00	$125,532
Sugarbeets	2007	Minnesota	486	451	25.80	11,445	$45.20	$517,450
Sugarbeets	2007	Montana	42	47	24.70	1,161	$39.10	$45,395
Sugarbeets	2007	Nebraska	42	44	25.50	1,041	$40.40	$42,056
Sugarbeets	2007	North Dakota	252	247	25.10	6,705	$46.30	$364,185
Sugarbeets	2007	Oregon	12	11	31.90	351	$36.90	$12,952
Sugarbeets	2007	United States	1,269	1,247	25.50	31,854	$42.00	$1,337,173
Sugarbeets	2007	Washington	2	2	42.00	84	$38.00	$3,190
Sugarbeets	2007	Wyoming	31	30	21.60	655	$40.20	$26,452
Sugarbeets	2008	California	43	43	35.10	1,556	$42.20	$65,665
Sugarbeets	2008	Colorado	42	38	23.40	859	$42.20	$37,516
Sugarbeets	2008	Idaho	188	187	31.70	5,925	$39.50	$234,156
Sugarbeets	2008	Michigan	156	154	23.20	3,573	$38.00	$135,774
Sugarbeets	2008	Minnesota	564	477	24.90	11,877	$46.70	$554,655
Sugarbeets	2008	Montana	54	49	27.00	1,319	$41.60	$54,496
Sugarbeets	2008	Nebraska	61	55	23.30	1,347	$44.50	$59,942
Sugarbeets	2008	North Dakota	261	243	26.00	6,315	$48.90	$308,850
Sugarbeets	2008	Oregon	13	13	30.10	394	$38.50	$15,503
Sugarbeets	2008	United States	1,366	1,304	26.10	34,064	$44.20	$1,506,065
Sugarbeets	2008	Washington	2	2	37.00	74	$38.50	$2,923
Sugarbeets	2008	Wyoming	43	40	19.90	795	$46.80	$37,348
Sugarbeets	2005	California	44	44	37.10	1,636	$41.80	$68,395
Sugarbeets	2005	Colorado	36	34	24.30	833	$40.70	$33,903
Sugarbeets	2005	Idaho	169	167	27.10	4,526	$44.40	$200,954
Sugarbeets	2005	Michigan	154	152	21.30	3,236	$34.40	$111,367
Sugarbeets	2005	Minnesota	491	460	20.40	9,384	$43.80	$411,019
Sugarbeets	2005	Montana	54	50	22.90	1,143	$45.30	$51,775
Sugarbeets	2005	Nebraska	48	45	20.40	924	$43.10	$39,824
Sugarbeets	2005	North Dakota	252	243	16.80	4,565	$49.20	$224,748
Sugarbeets	2005	Oregon	10	10	32.10	311	$44.40	$13,805
Sugarbeets	2005	United States	1,300	1,245	22.10	27,493	$43.50	$1,193,151
Sugarbeets	2005	Washington	2	2	40.60	69	$44.40	$3,064
Sugarbeets	2005	Wyoming	36	36	22.30	801	$42.20	$34,263

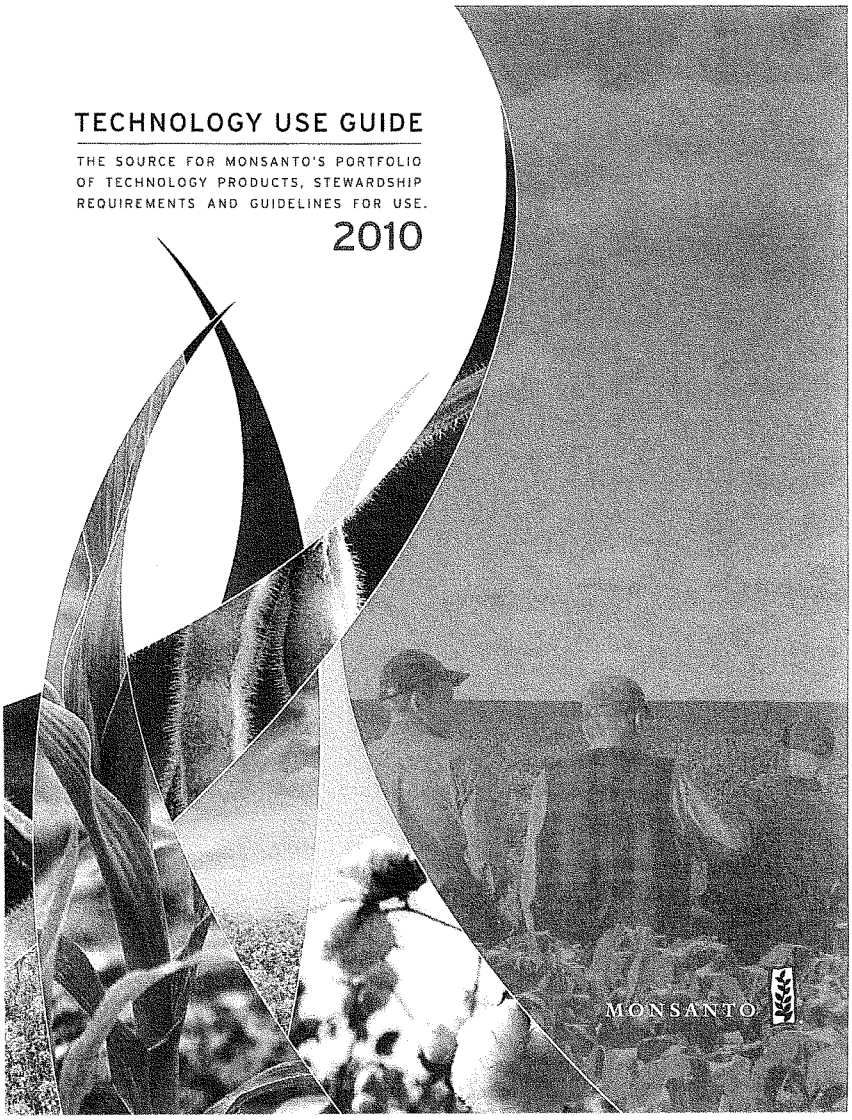
Commodity	Year	State	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons	Production (Thousands of Tons)	Price per Unit (Dollars per Ton)	Value of production (Thousands of Dollars)
Sugarbeets	2010	California	25					
Sugarbeets	2010	Colorado	30					
Sugarbeets	2010	Idaho	169					
Sugarbeets	2010	Michigan	147					
Sugarbeets	2010	Minnesota	445					
Sugarbeets	2010	Montana	42					
Sugarbeets	2010	Nebraska	46					
Sugarbeets	2010	North Dakota	227					
Sugarbeets	2010	Oregon	11					
Sugarbeets	2010	United States	1,174					
Sugarbeets	2010	Wyoming	32					
Sugarbeets	2009	California	25	25	35.00	880		
Sugarbeets	2009	Colorado	35	35	27.50	963		
Sugarbeets	2009	Idaho	164	163	34.30	5,601		
Sugarbeets	2009	Michigan	138	136	24.40	3,315		
Sugarbeets	2009	Minnesota	464	449	23.70	10,641		
Sugarbeets	2009	Montana	38	34	29.60	1,001		
Sugarbeets	2009	Nebraska	63	53	24.60	1,304		
Sugarbeets	2009	North Dakota	225	215	22.00	4,796		
Sugarbeets	2009	Oregon	11	11	37.60	395		
Sugarbeets	2009	United States	1,186	1,149	25.70	29,563		
Sugarbeets	2009	Wyoming	32	26	26.50	675		
Sugarbeets	2008	California	26	25	41.60	1,052	$44.80	$47,130
Sugarbeets	2008	Colorado	34	29	26.50	755	$47.80	$36,230
Sugarbeets	2008	Idaho	131	116	31.20	9,619	$42.00	$161,995
Sugarbeets	2008	Michigan	137	136	25.70	3,903	$44.00	$171,732
Sugarbeets	2008	Minnesota	440	399	24.70	9,855	$49.90	$491,765
Sugarbeets	2008	Montana	32	31	26.80	823	$50.80	$41,805
Sugarbeets	2008	Nebraska	45	37	22.60	843	$50.20	$42,324
Sugarbeets	2008	North Dakota	208	197	25.90	5,102	$51.00	$260,202
Sugarbeets	2008	Oregon	7	6	33.10	195	$42.00	$8,190
Sugarbeets	2008	United States	1,091	1,005	26.80	26,881	$48.00	$1,289,631
Sugarbeets	2008	Washington	2	2	41.90	87	$42.00	$2,614
Sugarbeets	2008	Wyoming	30	27	24.50	664	$52.80	$34,926
Sugarbeets	2007	California	40	39	35.50	1,386	$43.60	$60,517
Sugarbeets	2007	Colorado	32	29	26.20	765	$36.00	$27,540
Sugarbeets	2007	Idaho	189	167	34.40	5,745	$36.90	$211,991
Sugarbeets	2007	Michigan	150	149	23.40	3,487	$36.00	$125,532
Sugarbeets	2007	Minnesota	466	451	23.80	11,445	$45.20	$517,458
Sugarbeets	2007	Montana	48	47	24.70	1,161	$39.10	$45,395
Sugarbeets	2007	Nebraska	49	44	23.50	1,041	$40.40	$42,056
Sugarbeets	2007	North Dakota	229	247	23.10	5,706	$46.30	$264,185
Sugarbeets	2007	Oregon	12	11	31.90	351	$36.90	$12,952
Sugarbeets	2007	United States	1,269	1,247	25.50	31,834	$42.00	$1,337,173
Sugarbeets	2007	Washington	2	2	42.00	84	$36.90	$3,100
Sugarbeets	2007	Wyoming	31	30	21.80	655	$40.20	$26,462
Sugarbeets	2006	California	43	43	35.10	1,556	$42.20	$65,663
Sugarbeets	2006	Colorado	42	36	23.40	889	$42.20	$37,516
Sugarbeets	2006	Idaho	182	167	31.70	5,925	$39.50	$234,156
Sugarbeets	2006	Michigan	155	154	23.20	3,573	$38.00	$135,774
Sugarbeets	2006	Minnesota	504	477	24.90	11,877	$46.70	$554,656
Sugarbeets	2006	Montana	54	49	27.00	1,319	$41.60	$54,906
Sugarbeets	2006	Nebraska	61	55	23.30	1,347	$44.20	$59,942
Sugarbeets	2006	North Dakota	261	243	26.00	6,315	$48.90	$305,950
Sugarbeets	2006	Oregon	13	13	30.10	394	$39.50	$15,563
Sugarbeets	2006	United States	1,366	1,304	26.10	34,064	$44.20	$1,506,065
Sugarbeets	2006	Washington	2	2	37.05	74	$39.50	$2,923
Sugarbeets	2006	Wyoming	42	40	19.90	795	$46.80	$37,348
Sugarbeets	2005	California	44	44	37.10	1,636	$41.80	$68,355
Sugarbeets	2005	Colorado	36	34	24.50	833	$40.70	$33,903
Sugarbeets	2005	Idaho	169	167	27.10	4,526	$44.40	$200,954
Sugarbeets	2005	Michigan	154	153	21.30	3,235	$34.40	$111,357
Sugarbeets	2005	Minnesota	491	469	20.40	9,564	$43.00	$411,019
Sugarbeets	2005	Montana	54	50	22.90	1,143	$48.30	$55,775
Sugarbeets	2005	Nebraska	48	45	20.40	924	$43.10	$39,824
Sugarbeets	2005	North Dakota	255	243	16.60	4,565	$49.20	$224,748
Sugarbeets	2005	Oregon	10	10	32.10	311	$44.40	$13,805
Sugarbeets	2005	United States	1,300	1,243	22.10	27,433	$43.50	$1,193,151
Sugarbeets	2005	Washington	2	2	40.60	80	$44.40	$3,064
Sugarbeets	2005	Wyoming	36	36	22.30	801	$42.80	$34,263

Commodity	Year	State	Planted All Purposes (Thousands of Acres)	Harvested (Thousands of Acres)	Yield (Tons)	Production (Thousands of Tons)	Price per Unit (Dollars per Ton)	Value of production (Thousands of Dollars)
Sugarbeets	2010	California	25					
Sugarbeets	2010	Colorado	30					
Sugarbeets	2010	Idaho	162					
Sugarbeets	2010	Michigan	147					
Sugarbeets	2010	Minnesota	446					
Sugarbeets	2010	Montana	42					
Sugarbeets	2010	Nebraska	46					
Sugarbeets	2010	North Dakota	227					
Sugarbeets	2010	Oregon	11					
Sugarbeets	2010	United States	1,174					
Sugarbeets	2010	Wyoming	32					
Sugarbeets	2009	California	25	25	35.00	885		
Sugarbeets	2009	Colorado	35	35	37.60	963		
Sugarbeets	2009	Idaho	164	163	34.30	5,581		
Sugarbeets	2009	Michigan	138	136	24.40	3,315		
Sugarbeets	2009	Minnesota	464	449	23.70	10,641		
Sugarbeets	2009	Montana	38	34	29.60	1,001		
Sugarbeets	2009	Nebraska	53	53	24.60	1,304		
Sugarbeets	2009	North Dakota	225	215	22.00	4,795		
Sugarbeets	2009	Oregon	11	11	37.60	395		
Sugarbeets	2009	United States	1,185	1,142	25.70	29,563		
Sugarbeets	2009	Wyoming	32	26	26.50	675		
Sugarbeets	2008	California	26	25	41.60	1,052	$44.80	$47,150
Sugarbeets	2008	Colorado	34	29	26.50	765	$47.80	$36,232
Sugarbeets	2008	Idaho	131	116	31.20	5,619	$42.00	$161,995
Sugarbeets	2008	Michigan	137	136	25.70	3,903	$44.00	$171,732
Sugarbeets	2008	Minnesota	440	399	24.70	9,855	$49.90	$491,765
Sugarbeets	2008	Montana	33	31	26.80	833	$50.80	$41,905
Sugarbeets	2008	Nebraska	46	37	22.60	843	$50.20	$42,824
Sugarbeets	2008	North Dakota	208	197	25.90	5,103	$51.00	$260,202
Sugarbeets	2008	Oregon	7	6	33.10	195	$42.00	$8,190
Sugarbeets	2008	United States	1,091	1,005	26.60	26,881	$48.00	$1,289,821
Sugarbeets	2008	Washington	2	2	41.90	67	$42.00	$2,814
Sugarbeets	2008	Wyoming	30	27	24.50	664	$52.60	$34,926
Sugarbeets	2007	California	40	39	35.50	1,386	$43.60	$60,517
Sugarbeets	2007	Colorado	32	29	26.20	765	$36.00	$27,540
Sugarbeets	2007	Idaho	169	167	34.40	5,745	$36.60	$211,991
Sugarbeets	2007	Michigan	150	149	23.40	3,487	$36.00	$125,533
Sugarbeets	2007	Minnesota	486	461	25.80	11,445	$45.20	$517,450
Sugarbeets	2007	Montana	42	47	24.70	1,161	$39.10	$45,305
Sugarbeets	2007	Nebraska	42	44	23.50	1,041	$40.40	$42,056
Sugarbeets	2007	North Dakota	252	247	23.10	5,706	$46.30	$264,185
Sugarbeets	2007	Oregon	12	11	31.90	351	$36.80	$12,982
Sugarbeets	2007	United States	1,269	1,247	25.50	31,834	$42.00	$1,337,175
Sugarbeets	2007	Washington	2	2	42.00	84	$36.90	$3,100
Sugarbeets	2007	Wyoming	31	30	21.80	655	$40.20	$26,452
Sugarbeets	2006	California	43	43	35.10	1,555	$42.20	$65,663
Sugarbeets	2006	Colorado	43	38	23.40	889	$42.20	$37,516
Sugarbeets	2006	Idaho	182	167	31.70	5,935	$39.20	$234,156
Sugarbeets	2006	Michigan	155	154	23.20	3,573	$38.00	$135,774
Sugarbeets	2006	Minnesota	504	477	24.90	11,877	$46.70	$554,656
Sugarbeets	2006	Montana	54	49	27.00	1,319	$41.60	$54,906
Sugarbeets	2006	Nebraska	61	58	23.30	1,347	$44.50	$59,942
Sugarbeets	2006	North Dakota	261	243	25.03	6,315	$48.90	$305,950
Sugarbeets	2006	Oregon	13	13	30.10	394	$39.50	$15,563
Sugarbeets	2006	United States	1,366	1,334	26.10	34,864	$44.20	$1,506,995
Sugarbeets	2006	Washington	2	2	37.00	74	$39.60	$2,923
Sugarbeets	2006	Wyoming	43	40	19.90	795	$46.80	$37,345
Sugarbeets	2005	California	44	44	37.10	1,636	$41.80	$65,355
Sugarbeets	2005	Colorado	36	34	24.50	833	$40.70	$33,903
Sugarbeets	2005	Idaho	169	167	27.10	4,525	$44.40	$200,954
Sugarbeets	2005	Michigan	154	152	21.30	3,235	$34.40	$111,367
Sugarbeets	2005	Minnesota	491	460	20.40	9,384	$43.80	$411,019
Sugarbeets	2005	Montana	54	50	22.90	1,143	$45.30	$51,775
Sugarbeets	2005	Nebraska	42	45	20.40	934	$43.10	$39,824
Sugarbeets	2005	North Dakota	255	243	15.60	4,565	$49.20	$224,746
Sugarbeets	2005	Oregon	10	10	32.10	311	$44.40	$13,805
Sugarbeets	2005	United States	1,300	1,243	22.10	27,433	$43.50	$1,193,151
Sugarbeets	2005	Washington	2	2	40.60	69	$44.40	$3,064
Sugarbeets	2005	Wyoming	36	36	22.30	801	$42.80	$34,263

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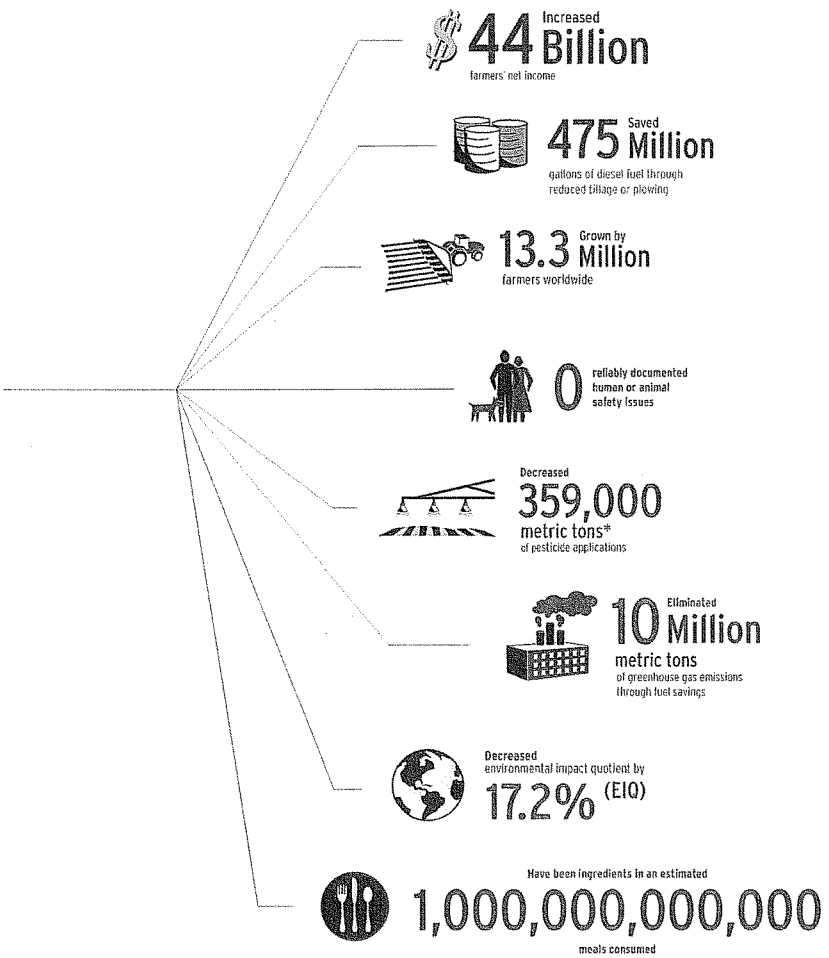
Appendix E

2010 Technology Use Guide


TECHNOLOGY USE GUIDE
THE SOURCE FOR MONSANTO'S PORTFOLIO OF TECHNOLOGY PRODUCTS, STEWARDSHIP REQUIREMENTS AND GUIDELINES FOR USE.
2010
MONSANTO

Since 1996, biotech crops have delivered environmental and economic benefits to both farmers and consumers.





Source: www.biotech-gmo.com

*Pesticides registered by the U.S. EPA will not cause unreasonable adverse effects to man or the environment when used in accordance with label directions.

RE:NEW

YOUR ABILITY TO ENHANCE YOUR CROPS TODAY!

It's time to ReNEW your license

If you haven't renewed your Monsanto Technology/Stewardship Agreement (MTSA) in the past nine months, **take care of it today!**

Signing the MTSA ensures you'll have access to current and next-wave technologies. These innovations will enhance plant drought tolerance, cold tolerance, nitrogen use efficiency, yield and much more!



CALL

1-800-768-6387, Option 3

You'll then have the option to complete the process online or through conventional mail.

Paper MTSA's will continue to be accepted.

Introduction

This 2010 Technology Use Guide (TUG) provides a concise source of technical information about Monsanto's current portfolio of technology products and sets forth requirements and guidelines for the use of these products. As a user of Monsanto Technology, it is important that you are familiar with and follow certain management practices. Please read all of the information pertaining to the technology you will be using, including stewardship and related information. Growers must read the Insect Resistance Management (IRM)/Grower Guide prior to planting for important information on planting and IRM.

This technical guide is not a pesticide product label. It is intended to provide additional information and to highlight approved uses from the product labeling. Read and follow all precautions and use instructions in the label booklet and separately published supplemental labeling for the Roundup® agricultural herbicide product you are using.

Included in this guide is information on the following:

Stewardship Overview	4
Introducing Genuity™	6
Insect Resistance Management	8
Weed Management	10
Coexistence and Identity Preserved Production	12
Corn Technologies	15
YieldGard® and Genuity™ Corn Technologies Product Descriptions	
Roundup Ready® Technology in Corn	
Cotton Technologies	21
Genuity™ Bollgard II® and Bollgard® Cotton	
Roundup Ready Technologies in Cotton	
Genuity™ Roundup Ready 2 Yield® and Roundup Ready Soybeans	31
Genuity™ Roundup Ready® Alfalfa	35
Genuity™ Roundup Ready® Spring Canola	38
Genuity™ Roundup Ready® Winter Canola	39
Genuity™ Roundup Ready® Sugarbeets	40

If you have any questions, contact your Authorized Retailer or Monsanto at 1-800-768-6387.

STEWARDSHIP OVERVIEW

A Message About Stewardship - SEED AND TRAITS

Monsanto Company is committed to enhancing farmer productivity and profitability through the introduction of new agricultural biotechnology traits. These new technologies bring enhanced value and benefits to farmers, and farmers assume new responsibilities for proper management of these traits. Farmers planting seed with biotech traits agree to implement good stewardship practices, including, but not limited to:

- Reading, signing and complying with the Monsanto Technology/Stewardship Agreement (MTSA) and reading all annual license terms updates before purchase or use of any seed containing a trait.
- Reading and following the directions for use on all product labels.
- Following applicable stewardship practices as outlined in this TUG.
- Reading and following the IRM/Grower Guide prior to planting.
- Observing regional planting restrictions mandated by the U.S. Environmental Protection Agency (EPA).
- Complying with any additional stewardship requirements, such as grain or feed use agreements or geographical planting restrictions, that Monsanto deems appropriate or necessary to implement for proper stewardship or regulatory compliance.
- Following the Weed Resistance Management Guidelines to minimize the risk of resistance development.
- Complying with the applicable IRM practices for specific biotech traits as *mandated* by the EPA and set forth in this TUG.
- Utilizing all seed with biotech traits only for planting a single crop.
- Selling crops or material containing biotech traits only to grain handlers that confirm their acceptance, or using those products on farm.
- Not moving material containing biotech traits across boundaries into nations where import is not permitted.
- Not selling, promoting and/or distributing within a state where the product is not yet registered.

CROP OR MATERIAL HANDLING STEWARDSHIP STATEMENT

Monsanto Company is a member of Excellence Through Stewardship® (ETS). Monsanto products are commercialized in accordance with ETS Product Launch Stewardship Guidance, and in compliance with Monsanto's Policy for Commercialization of Biotechnology-Derived Plant Products in Commodity Crops. This product has been approved for import into key export markets with functioning regulatory systems. Any crop or material produced from this product can only be exported to, or used, processed or sold in countries where all necessary regulatory approvals have been granted. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Growers should talk to their grain handler or product purchaser to confirm their buying position for this product. Excellence Through Stewardship® is a registered trademark of Biotechnology Industry Organization.

WHY IS STEWARDSHIP IMPORTANT?

Each component of stewardship offers benefits to farmers:

- Signing the MTSA provides farmers access to Monsanto's biotech trait seed technology.
- Following IRM guidelines guards against insect resistance to *Bacillus thuringiensis (B.t.)* technology and therefore enables the long-term viability of this technology, and meets EPA requirements.
- Proper weed management maintains the long-term effectiveness of glyphosate-based weed control solutions.
- Utilizing biotech seed only for planting a single-commercial crop helps preserve the effectiveness of biotech traits, while allowing investment for future biotech innovations which further improves farming technology and productivity.

Practicing these stewardship activities will enable biotechnology's positive agricultural contributions to continue.

Farmers' attitudes and adoption of sound stewardship principles, coupled with biotechnology benefits, provide for the sustainability of our land resources, biotechnology and farming as a preferred way of life.

SEED PATENT INFRINGEMENT

If Monsanto reasonably believes that a farmer has planted saved seed containing a Monsanto biotech trait, Monsanto will request invoices and records to confirm that fields in question have been planted with newly purchased seed. If this information is not provided within 30 days, Monsanto may inspect and test all of the farmer's fields to determine if saved seed has been planted. Any inspections will be coordinated with the farmer and performed at a reasonable time to best accommodate the farmer's schedule.

If you have questions about seed stewardship or become aware of individuals utilizing biotech traits in a manner other than as noted above, please call 1-800-768-6387. Letters reporting unacceptable or unauthorized use of biotech traits may be sent to:

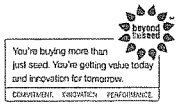
Monsanto Trait Stewardship
800 N. Lindbergh Boulevard NC3C
St. Louis, MO 63167

For more information on Monsanto's practices related to seed patent infringement, please visit: www.monsanto.com/seedpatentprotection.

Provide Anonymous or Confidential reports as follows:

"Anonymous" reporting results when a person reports information to Monsanto in such a way that the identity of the person reporting the information cannot be identified. This kind of reporting includes telephone calls requesting anonymity and unsigned letters.

"Confidential" reporting results when a person reports information to Monsanto in such a way that the reporting person's identity is known to Monsanto. Every effort will be made to protect a person's identity, but it is important to understand that a court may order Monsanto to reveal the identity of people who are "known" to have supplied relevant information.



The Beyond the Seed Program was launched by the American Seed Trade Association (ASTA) to raise awareness and understanding of the value that goes beyond the seed. The future success of U.S. agriculture depends upon quality seed delivered by an industry commitment to bring innovation and performance through continued investment. For more information about seed technology, visit ASTA's Beyond the Seed Program at www.beyondtheseed.org.

INTRODUCING GENUITY™

Genuity™ Unites the Best Traits*

As a purchaser of Monsanto biotech trait products, your investment helps fuel the research and development engine that leads to the discovery and delivery of new technologies for agriculture. Current and future Genuity™ traits are designed to deliver high yield potential, maximize return on seed investments and consistently deliver future trait innovations.

CORN

Higher yields come from quality grain. Genuity™ VT Triple PRO™ was the next generation of corn technology available for the 2009 growing season. Genuity™ VT Triple PRO™ provides dual modes of action against above-ground pests such as corn earworm, European and southwestern corn borers, sugarcane borer, southern cornstalk borer and fall armyworm. Reduced kernel damage from corn earworm means the potential for reduced Aflatoxin contamination. Genuity™ VT Triple PRO™ dual modes-of-action also allows for a reduction in refuge acres required in southern cotton-growing regions while providing long-term effectiveness and consistency.

GENUITY™ SMARTSTAX™

Scheduled for launch in 2010, Genuity™ SmartStax™ is the most-advanced, all-in-one corn trait system that controls the broadest spectrum of above- and below-ground insects and weeds. Genuity™ SmartStax™ provides control of corn earworm, European corn borer, southwestern corn borer, sugarcane borer, fall armyworm, western bean cutworm, black cutworm, western corn rootworm, northern corn rootworm and Mexican corn rootworm. Genuity™ SmartStax™ contains Roundup Ready® 2 Technology and LibertyLink® herbicide tolerance. Genuity™ SmartStax™ also allows for a reduction in refuge acres in the corn belt from 20% down to 5% for above- and below-ground refuge. Genuity™ SmartStax™ is also approved for a 20% refuge in the cotton belt.

SOYBEAN

Genuity™ Roundup Ready 2 Yield® soybeans are taking yield to a higher level. They were developed to provide farmers with the same simple, dependable and flexible weed control and crop safety they've come to rely on with the first-generation Roundup Ready® soybean system, but with higher yield potential. This is possible because of advanced insertion and selection technologies.

COTTON

Genuity™ Roundup Ready® Flex and Genuity™ Bollgard II® offer the ultimate combination of peace of mind and flexibility. They contain unrivaled built-in worm control to stop the most leaf- and boll-feeding worm species, including bollworms, budworms, armyworms, loopers, saltmarsh caterpillars and cotton leaf perforators. Protecting just one additional boll per plant can result in significantly higher lint yield. The convenience and savings from fewer or no sprays for worms can make a big difference when it comes to the bottom line.

SPECIALTY

Genuity™ Roundup Ready® alfalfa: Bred from an innovative germplasm pool, it offers outstanding weed control, excellent crop safety and preservation of forage quality potential.

Genuity™ Roundup Ready® canola: Offers excellent control of broadleaf weeds and grasses, even in tough weather conditions. Also features excellent crop safety and broad application flexibility.

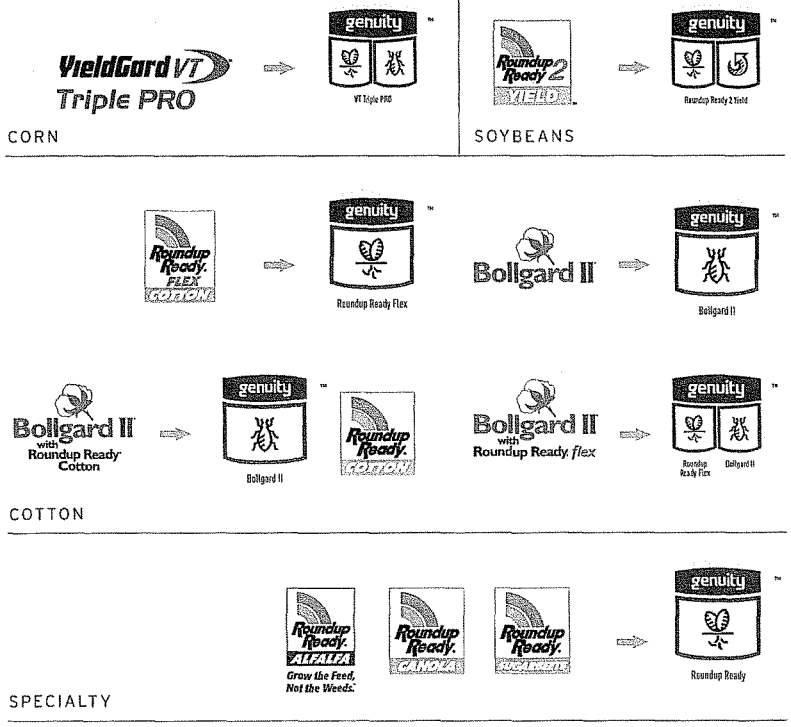
Genuity™ Roundup Ready® sugarbeets: Excellent in-plant tolerance to over-the-top applications of labeled Roundup agricultural herbicides. Offers outstanding weed control, excellent crop safety and preservation of yield potential.

*See pages 16 and 17 for additional traits.

NOTE: Farmers must read the IRM/Grower Guide prior to planting for information on planting and Insect Resistance Management.

Monsanto's New Generation of Technologies

As Monsanto continues to develop new generations of technologies, several of our newer technologies are migrating to the Genuity™ brand. These products and their new logos are presented below.



INSECT RESISTANCE MANAGEMENT (IRM)



An **EFFECTIVE** IRM program is a vital part of responsible product stewardship for insect-protected biotech products. Monsanto is committed to implementing an effective IRM program for all of its insect-protected *B.t.* technologies in all countries where they are commercialized, including promoting farmer awareness of these IRM programs. Monsanto works to develop and implement IRM programs that strike a balance between available knowledge and practicality, with farmer acceptance and implementation of the plan as critical components.

The U.S. EPA requires that Monsanto implement, and farmers who purchase insect-protected products follow, an IRM plan.* IRM programs for *B.t.* traits are based upon an assessment of the biology of the major target pests, farmer needs and practices, and appropriate pest management practices. These **mandatory regulatory programs** have been developed and updated through broad cooperation with farmer and consultant organizations, including the National Corn Growers Association and the National Cotton Council, extension specialists, academic scientists, and regulatory agencies.

*In some areas, a natural refuge option is available for Bollgard II. See the current IRM/Grower Guide for details.

The IRM programs for planting seeds containing *B.t.* traits contain several important elements. One key component of an IRM plan is a refuge. A refuge is simply a portion of the relevant crop (corn or cotton) that does not contain a *B.t.* technology for the control of the insect pests which are controlled by the planted technology(ies). The lack of exposure to the *B.t.* proteins means that there will be susceptible insects nearby to mate with any rare resistant insects that may emerge from *B.t.* products. Susceptibility to *B.t.* products is then passed on to offspring, preserving the long-term effectiveness of the technology.

Farmers who purchase seeds containing *B.t.* traits must plant an appropriately designed refuge. Refuge size, configuration, and management is described in detail in the sections on those products in the 2010 IRM/Grower Guide.

Failure to follow IRM requirements and to plant a proper refuge may result in the loss of a farmer's access to Monsanto technologies. Monsanto is committed to the preservation of *B.t.* technologies. Please do your part to preserve *B.t.* technologies by implementing the correct IRM plan on your farm.

MONITORING PROGRAM

The U.S. EPA requires Monsanto to take corrective measures in response to a finding of IRM non-compliance. Monsanto or an approved agent of Monsanto must monitor refuge management practices. The MTSA signed by a farmer requires that upon request by Monsanto or its approved agent, a farmer must provide the location of all fields planted with Monsanto technologies and the locations of all associated refuge areas as required, to cooperate fully with any field inspections, and allow Monsanto to inspect all fields and refuge areas to ensure an approved insect resistance program has been followed. All inspections will be performed at a reasonable time and arranged in advance with the farmer so that the farmer can be present if desired.

IRM GUIDELINES

Farmers must read the current IRM/Grower Guide prior to planting for information on planting and IRM. If you do not have a copy of the current IRM/Grower Guide, you may downloaded it at **www.monsanto.com**, or you may call 1-800-768-6387 to request a copy by mail.





WEED MANAGEMENT

Monsanto considers product stewardship to be a fundamental component of customer service and responsible business practices. As leaders in the development and stewardship of Roundup® agricultural herbicides and other products, Monsanto invests significantly in research to continuously improve the proper uses and stewardship of our proprietary herbicide brands.

This research, done in conjunction with academic scientists, extension specialists and crop consultants, includes an evaluation of the factors that can contribute to the development of weed resistance and how to properly manage weeds to delay the selection for weed resistance. Visit **www.weedtool.com** for practical, best practices-based information on reducing the risk for development of glyphosate-resistant weeds. Developed in cooperation with academic experts, the website provides options for managing the risk on a field-by-field basis.

Glyphosate is a Group 9 herbicide based on the mode of action classification system of the Weed Science Society of America. Any weed population may contain plants naturally resistant to Group 9 herbicides. The following general recommendations help manage the risk of weed resistance occurring.

WEED RESISTANCE MANAGEMENT PRACTICES:

- Scout your fields before and after herbicide application
- Start with a clean field, using either a burndown herbicide application or tillage
- Control weeds early when they are small
- Add other herbicides (e.g. a selective in-crop and/or a residual herbicide) and cultural practices (e.g. tillage or crop rotation) as part of your Roundup Ready® cropping system where appropriate
- Rotation to other Roundup Ready crops will add opportunities for introduction of other modes of action
- Use the right herbicide product at the right rate and the right time
- Control weed escapes and prevent weeds from setting seeds
- Clean equipment before moving from field to field to minimize spread of weed seed
- Use new commercial seed that is as free from weed seed as possible

Monsanto is committed to the proper use and long-term effectiveness of its proprietary herbicide brands through a four-part stewardship program: developing appropriate weed control recommendations, continuing research to refine and update recommendations, education on the importance of good weed management practices and responding to repeated weed control inquiries through a product performance evaluation program.

GLYPHOSATE-RESISTANT WEEDS

Monsanto actively investigates and studies weed control complaints and claims of weed resistance. When glyphosate-resistant weed biotypes have been confirmed, Monsanto alerts farmers and develops and provides farmers with recommended control measures, which may include additional herbicides, tank-mixes or cultural practices. Monsanto actively communicates all of this information to farmers through multiple channels, including the herbicide label, **www.weedscience.org**, supplemental labeling, this TUG, media and written communications, Monsanto's website, **www.weedresistancemanagement.com**, and farmer meetings.

Farmers must be aware of, and proactively manage for, glyphosate-resistant weeds in planning their weed control program. When a weed is known to be resistant to glyphosate, then a resistant population of that weed is by definition no longer controlled with labeled rates of glyphosate. Roundup® agricultural herbicide warranties will not cover the failure to control glyphosate-resistant weed populations.

Report any incidence of repeated non-performance on a particular weed to your local Monsanto representative, retailer or county extension agent.

Note: Always read and follow all pesticide label requirements.

ROUNDUP BRAND AGRICULTURAL OVER-THE-TOP HERBICIDE PRODUCTS

Read and follow all product labeling before using Roundup agricultural herbicides over the top of products with Roundup Ready Technology.

You may use another glyphosate herbicide, but only if it has federally approved label instructions for use over that specific Roundup Ready crop, and the product and the use label for that Roundup Ready crop has been approved by your specific state. Contact the product manufacturers, the local retailers or the local extension agents for confirmation that the products carry EPA and state approved labeling for this use. **MONSANTO DOES NOT MAKE ANY REPRESENTATIONS, WARRANTIES OR RECOMMENDATIONS CONCERNING THE USE OF GLYPHOSATE PRODUCTS SUPPLIED BY OTHER COMPANIES WHICH ARE LABELED FOR USE OVER ROUNDUP READY CROPS. MONSANTO SPECIFICALLY DENIES ALL RESPONSIBILITY AND DISCLAIMS ANY LIABILITY FOR ANY DAMAGE FROM THE USE OF THESE PRODUCTS IN ROUNDUP READY CROPS. ALL QUESTIONS AND COMPLAINTS CAUSED BY THE USE OF GLYPHOSATE PRODUCTS SUPPLIED BY OTHER COMPANIES SHOULD BE DIRECTED TO THE SUPPLIER OF THE PRODUCT IN QUESTION.**

MONSANTO BRANDS OF SELECTIVE OVER-THE-TOP HERBICIDE PRODUCTS

Herbicide products sold by Monsanto for use over the top of Roundup Ready crops for the 2010 crop season are as follows:

Roundup WeatherMAX®

Roundup PowerMAX®

Read and follow all product labeling before using Roundup agricultural herbicides over the top of Roundup Ready traits. To learn more about applicable supplemental labels or fact sheets, call 1-800-768-6387.

Tank-mixtures of Roundup agricultural herbicides with insecticides, fungicides, micronutrients or foliar fertilizers are not recommended as they may result in reduced weed control, crop injury, reduced pest control or antagonism. Refer to the Roundup agricultural herbicide product label, supplemental labeling or fact sheets published separately by Monsanto for tank-mix recommendations.

Do not add additional surfactants and/or products containing surfactants to these Roundup agricultural herbicides unless otherwise directed by the label. Other glyphosate products labeled for use in Roundup Ready technologies may require the addition of surfactants, or other additives to optimize performance, that may increase the potential for crop injury. Monsanto will label and promote only fully tested brands that do not require surfactants and other additives for over-the-top applications to Roundup Ready Crops.

GLYPHOSATE ENDANGERED SPECIES INITIATIVE

Before making applications of glyphosate-based herbicide products, licensed farmers of crops containing Roundup Ready technology must access the website **www.pre-serve.org** to determine whether any mitigation requirements apply to the planned application to those crops, and must follow all applicable requirements. The mitigation measures described on the website are appropriate for all applications of glyphosate-based herbicides to all crop lands.

Farmers making only ground applications to crop land with a use rate of less than 3.5 lbs of glyphosate a.e./A are not required to access the website. If a farmer does not have web access, the seed dealer can access the website on behalf of the farmer to determine the applicable requirements, or the farmer can call 1-800-332-3111 for assistance.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS IN ROUNDUP READY CROPS

In certain areas, populations of ryegrass, johnsongrass, marestail, common ragweed, giant ragweed, *Palmer Amaranth* and waterhemp are known to be resistant to glyphosate. For control recommendations for resistant biotypes of these weeds, refer to www.weedresistancemanagement.com or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on www.cdms.net or www.greenbook.net or obtained by calling 1-800-768-6387.

COEXISTENCE AND IDENTITY PRESERVED PRODUCTION

Coexistence in agricultural production systems and supply chains is not new. Different agricultural systems have coexisted successfully for many years around the world. Standards and best practices were established decades ago and have continually evolved to deliver high purity seed and grain to support production, distribution and trade of products from different agricultural systems. For example, production of similar commodities such as field corn, sweet corn and popcorn has occurred successfully and in close proximity for many years. Another example is the successful coexistence of oilseed rape varieties with low erucic acid content for food use and high erucic acid content for industrial uses.

The introduction of biotech crops generated renewed discussion of coexistence focused on biotech production systems with conventional cropping systems and organic production. These discussions have primarily focused on the potential economic impact of the introduction of biotech products on other systems. The health and safety of biotech products are not an issue because their food, feed and environmental safety must be demonstrated before they enter the agricultural production system and supply chain.

The coexistence of conventional, organic and biotech crops has been the subject of several studies and reports. These reports conclude that coexistence among biotech and non-biotech crops is not only possible but is occurring. They recommend that coexistence strategies be developed on a case-by-case basis considering the diversity of products currently in the market and under development, the agronomic and biological differences in the crops themselves and variations in regional farming practices and infrastructures. Furthermore, coexistence strategies are driven by market needs and should be developed using current science-based industry standards and management practices. The strategies must be flexible, facilitating options and choice for the farmer and the food/feed supply chain, and must be capable of being modified as changes in markets and products warrant.

Successful coexistence of all agricultural systems is achievable and depends on cooperation, flexibility and mutual respect for each system. Agriculture has a history of innovation and change, and farmers have always adapted to new approaches or challenges by utilizing appropriate strategies, farm management practices and new technologies.

The responsibility for implementing practices to satisfy specific marketing standards or certification lies with that farmer who is growing a crop to satisfy a particular market. Only that farmer is instructed to employ the practices appropriate to assure the integrity of his/her crop. This is true whether the goal is high-oil corn, white/sweet corn or organically produced yellow corn for animal feed. In each case, the farmer is seeking to produce a crop that is supported by a market price and consequently that farmer assumes responsibility for satisfying reasonable market specifications. That said, the farmer needs to be aware of the planting intentions of his/her neighbor in order to gauge the need for management practices.

IDENTITY PRESERVED PRODUCTION

Some farmers may choose to preserve the identity of their crops to meet specific markets. Examples of Identity Preserved (I.P.) corn crops include production of seed corn, white, waxy or sweet corn, specialty oil or protein crops, food grade crops and any other crop that meets specialty needs, including organic and non-genetically enhanced specifications. Farmers of these crops assume the responsibility and receive the benefit for ensuring that their crop meets mutually agreed contract specifications.

Based on historical experience with a broad range of I.P. crops, the industry has developed generally accepted I.P. agricultural practices. These practices are intended to manage I.P. production to meet quality specifications, and are established for a broad range of I.P. needs. The accepted practice with I.P. crops is that each I.P. farmer has the responsibility to implement any necessary processes. These processes may include sourcing seed appropriate for I.P. specifications, field management practices such as adequate isolation distances, buffers between crops, border rows, planned differences in maturity between adjacent fields that might cross-pollinate and harvest and handling practices designed to prevent mixing and to maintain product quality. These extra steps associated with I.P. crop production are generally accompanied by incremental increases in cost of production and consequently of the goods sold.

General Instructions for Management of Pollen Flow and Mechanical Mixing

For all crop hybrids or varieties that they wish to identity preserve, or otherwise keep separated, farmers should take steps to prevent mechanical mixing. Farmers should make sure all seed storage areas, transportation vehicles and planter boxes are cleaned thoroughly both prior to and subsequent to the storage, transportation or planting of the crop. Farmers should also make sure all combines, harvesters and transportation vehicles used at harvest are cleaned thoroughly both prior to and subsequent to their use in connection with the harvest of the grain produced from the crop. Farmers should also make sure all harvested grain is stored in clean storage areas where the identity of the grain can be preserved.

Self-pollinated crops, such as soybeans, do not present a risk of mixing by cross-pollination. If the intent is to use or market the product of a self-pollinated crop separately from general commodity use, farmers should plant fields a sufficient distance away from other crops to prevent mechanical mixture.

Farmers planting cross-pollinated crops, such as corn or alfalfa, who desire to preserve the identity of these crops, or to minimize the potential for these crops to outcross with adjacent fields of the same crop kind, should use the same generally accepted practices to manage mixing that are used in any of the currently grown I.P. crops of similar crop kind.

It is generally recognized in the industry that a certain amount of incidental, trace level pollen movement occurs, and it is not possible to achieve 100% purity of seed or grain in any corn production system. A number of factors can influence the occurrence and extent of pollen movement. As stewards of technology, farmers are expected to consider these factors and talk with their neighbors about their cropping intentions.

Farmers should take into account the following factors that can affect the occurrence and extent of cross-pollination to or from other fields. Information that is more specific to the crop and region may be available from state extension offices.

- Cross-pollination is limited. Some plants, such as potatoes, are incapable of cross-pollinating, while others, like alfalfa, require cross-pollination to produce seed. Importantly, cross-pollination only occurs within the same crop kind, like corn to corn.
- The amount of pollen produced within the field can vary. The pollen produced by the crop within a given field, known as pollen load, is typically high enough to pollinate all of the plants in the field. Therefore, most of the pollen that may enter from other fields falls on plants that have already been pollinated with pollen that originated from plants within the field. In crops such as alfalfa, the hay cutting management schedule significantly limits or eliminates bloom, and thereby restricts the potential for pollen and/or viable seed formation.
- The existence and/or degree of overlap in the pollination period of crops in adjacent fields varies. This will vary depending on the maturity of crops, planting dates and the weather. For corn, the typical pollen shed period lasts from 5 to 10 days for a particular field. Therefore, viable pollen from neighboring fields must be present when silks are receptive in the recipient field during this brief period to produce any grain with traits introduced by the out-of-field pollen.
- Distance between fields of different varieties or hybrids of the same crop: The greater the distance between fields the less likely their pollen will remain viable and have an opportunity to mix and produce an outcross. For wind-pollinated crops, most cross-pollination occurs within the outermost few rows of the field. In fact, many white and waxy corn production contracts ask the farmer to remove the outer 12 rows (30 ft.) of the field in order to remove most of the impurities that could result from cross-pollination with nearby yellow dent corn. Furthermore, research has also shown that as fields become further separated, the incidence of wind-modulated cross-pollination drops rapidly. Essentially, the in-field pollen has an advantage over the pollen coming from other fields for receptive silks because of its volume and proximity to silks.
- The distance pollen moves. How far pollen can travel depends on many environmental factors, including weather during pollination, especially wind direction and velocity, temperature and humidity. For bee-pollinated crops, the farmer's choice of pollinator species and aplary management practice may reduce field-to-field pollination potential. All these factors will vary from season to season, and some factors from day to day and from location to location.
- For wind-pollinated crops, the orientation and width of the adjacent field in relation to the dominant wind direction. Fields oriented upwind during pollination will show dramatically lower cross-pollination for wind-pollinated crops, like corn, compared to fields located downwind.



CORN TECHNOLOGIES

Advanced breeding and biotechnology have had a major impact on farming production. From 1971 to 1995, average corn yields were increasing at a rate of 1.5 bushels per acre, per year. Since the advent of biotech in 1996, corn yields have increased at a rate of 2.6 bushels per acre, per year, for a total increase of 32 bushels per acre.*

Excellence Through Stewardship

Monsanto Company is a member of Excellence Through Stewardship® (ETS). Monsanto products are commercialized in accordance with ETS Product Launch Stewardship Guidance, and in compliance with Monsanto's Policy for Commercialization of Biotechnology-Derived Plant Products in Commodity Crops. This product has been approved for import into key export markets with functioning regulatory systems. Any crop or material produced from this product can only be exported to, or used, processed or sold in countries where all necessary regulatory approvals have been granted. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Growers should talk to their grain handler or product purchaser to confirm their buying position for this product. Excellence Through Stewardship® is a registered trademark of Biotechnology Industry Organization.

IRM GUIDELINES

For specific refuge requirements for *B.t.* corn and cotton, see the current IRM/Grower Guide, sent with this TUG. If you have not received a copy of this Guide, it can be downloaded at www.monsanto.com, or call 1-800-768-6387 to request a copy be mailed to you.



Before opening a bag of seed, be sure to read and understand the stewardship requirements, **including applicable refuge requirements for insect resistance management,** for the biotechnology traits expressed in the seed as set forth in the Monsanto Technology Agreement that you sign. By opening and using a bag of seed, you are reaffirming your obligation to comply with those stewardship requirements.

* USDA Yields were calculated using 3 year rolling averages (32 Yield is 2.6 bu/ac *12 years). 2008 Yield is from Doane Ag Services forecast in April 8, 2008 Quarterly Crop Outlook.

Genuity™ Trait Products and YieldGard® Corn Technologies Product Descriptions

GENUITY™ SMARTSTAX™

Scheduled to launch in 2010, Genuity™ SmartStax™ is the most advanced, all-in-one corn trait system that controls the broadest spectrum of above- and below-ground insects and weeds. Genuity™ SmartStax™ hybrids will contain *B.t.* proteins that represent three separate modes of action for control of lepidopteron, above-ground insect pests, as well as combined modes of action for control of coleopteran, below-ground insect pests. Providing multiple *B.t.* proteins for control will dramatically decrease the probability that insects will become resistant to the traits, resulting in enhanced durability of transgenic insect control via *B.t.* genes. Based on this multiple gene approach, Genuity™ SmartStax™ is approved for reduced refuge in the corn belt from 20% down to 5% for both above- and below-ground pests. The cotton belt refuge for Genuity SmartStax™ is also reduced, from 50% down to 20%.

GENUITY™ VT TRIPLE PRO™

(Formerly YieldGard VT Triple PRO™) — Genuity™ VT Triple PRO™ is available in selected southern corn- and cotton-growing areas. It includes broad-spectrum insect control against corn earworm, European and southwestern corn borers, sugarcane borer, southern cornstalk borer, fall armyworm, western corn rootworm, northern corn rootworm and Mexican corn rootworm. Its advanced control of ear pests can result in higher grain quality and higher-yielding crop potential. The dual mode-of-action of Genuity™ VT Triple PRO™ allows for lower corn borer refuge acres in southern cotton-growing areas compared to other registered *B.t.*-traited products. It includes the same Roundup Ready® 2 Technology as Monsanto's previous product, YieldGard VT Triple. Seed containing Genuity™ VT Triple PRO™ technology is treated with seed-applied insecticide.*

YIELDGARD VT TRIPLE®

YieldGard VT Triple technology combines YieldGard Corn Borer and YieldGard VT Rootworm/RR2® technology into a single plant. YieldGard VT Triple corn hybrids control European and southwestern corn borer, sugarcane borer, southern cornstalk borer, western corn rootworm, northern corn rootworm and Mexican corn rootworm. YieldGard VT Triple technology suppresses corn earworm, fall armyworm and stalk borer. By providing in-plant protection against the above insect pests, the genetic yield potential of YieldGard VT Triple corn hybrids is preserved. YieldGard VT Triple corn hybrids also include Roundup Ready 2 Technology. This trait allows a farmer to experience the benefits of utilizing Roundup agricultural herbicides in a weed control system that provides the broadest weed control spectrum available, better application flexibility, and superior crop safety. Seed containing YieldGard VT Triple technology is treated with seed-applied insecticide.*

GENUITY™ VT DOUBLE PRO™

Genuity™ VT Double PRO™ is a new corn technology scheduled for launch in 2010. It includes broad-spectrum insect control against corn earworm, European and southwestern corn borers, sugarcane borer, southern cornstalk borer and fall armyworm. The dual mode-of-action of Genuity™ VT Double PRO™ allows for lower corn borer refuge acres compared to other registered *B.t.*-traited products. Seed containing Genuity™ VT Double PRO™ technology is treated with seed-applied insecticide.*

*A seed-applied insecticide can protect seed, roots and seedlings from insects such as black cutworm, wireworm, white grubs, seed corn maggots, chinch bug and early flea beetles.

YieldGard VT Rootworm/RR2

YIELDGARD VT ROOTWORM/RR2®

YieldGard VT Rootworm/RR2 technology is the current YieldGard stacked-trait product for control of western corn rootworm, northern corn rootworm and Mexican corn rootworm. Protecting the root of the corn plant from feeding by corn rootworm larvae decreases lodging and protects the genetic yield potential of YieldGard VT Rootworm/RR2 corn hybrids. The Roundup Ready 2 Technology allows a farmer to experience the benefits of utilizing Roundup agricultural herbicides in a weed control system that provides the broadest weed control spectrum, better application flexibility and superior crop safety. Seed containing YieldGard VT Rootworm/RR2 technology is treated with seed-applied insecticide.*

YIELDGARD® CORN BORER

YieldGard Corn Borer corn hybrids contain an insecticidal protein from *B.t.* that protects corn plants from European corn borer, southwestern corn borer, sugarcane borer and southern cornstalk borer resulting in full yield potential.

YIELDGARD® CORN BORER WITH ROUNDUP READY® CORN 2

YieldGard Corn Borer with Roundup Ready Corn 2 offers farmers all the benefits of both traits combined in one crop. These hybrids exhibit the same insect protection qualities as YieldGard Corn Borer and, like Roundup Ready Corn 2, are tolerant to over-the-top applications of Roundup® agricultural herbicides.

YIELDGARD PLUS

YieldGard Plus corn technology combines YieldGard Corn Borer and YieldGard Rootworm technology into a single plan.

YIELDGARD PLUS WITH ROUNDUP READY CORN 2

YieldGard Plus with Roundup Ready Corn 2 offers farmers all the benefits of all three traits combined in one crop. These hybrids exhibit the same insect protection qualities of YieldGard Corn Borer and YieldGard Rootworm and, like Roundup Ready Corn 2, are tolerant to over-the-top applications of Roundup® agricultural herbicides. Seed containing YieldGard Plus technology is treated with seed-applied insecticide.*

YIELDGARD ROOTWORM

YieldGard Rootworm corn hybrids contain an insecticidal protein from *B.t.* that protects corn roots from larval feeding by western, northern and Mexican corn rootworm.

YIELDGARD ROOTWORM WITH ROUNDUP READY CORN 2

YieldGard Rootworm with Roundup Ready Corn 2 offers farmers all the same insect protection qualities as YieldGard Rootworm and, like Roundup Ready Corn 2, is tolerant to over-the-top applications of Roundup agricultural herbicides.

*A seed-applied insecticide can protect seed, roots and seedlings from insects such as black cutworm, wireworm, white grubs, seed corn maggots, chinch bug and early flea beetles.

ROUNDUP READY® Technology in Corn

WEED CONTROL RECOMMENDATIONS

Roundup Ready® Corn 2 (RR2) and corn with Roundup Ready® 2 Technology are equivalent in their tolerance to Roundup agricultural herbicides. Products with Roundup Ready Technology contain in-plant tolerance to Roundup agricultural herbicides.

The Roundup Ready® Technology system's flexibility, broad-spectrum weed control and proven crop safety offer farmers weed control programs that allow them to use the system in the way that provides the greatest benefit. Farmers can select the program that best fits the way they farm. Options include the use of a residual herbicide with a Roundup® agricultural herbicide, tank-mixing other herbicides with Roundup agricultural herbicides where appropriate and a total postemergence program.

AGRONOMIC PRINCIPLES

Corn yield is very sensitive to early-season weed competition. Weed control systems must provide farmers the opportunity to control weeds before they become competitive. The Roundup Ready Technology system provides a mechanism to control weeds at planting and once they emerge. Farmers are provided excellent crop safety and full yield potential, with applications made from planting through 48" of corn height. Drop nozzles must be used between 30" and 48" of corn height. Failure to control weeds with the right rate, at the right time and with the right product, can lead to increased weed competition, weed escapes and the potential for decreased yields. Use other approved herbicide products with Roundup agricultural herbicides if appropriate for the weed spectrum.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
For use where residual herbicides are typically used for early-season weed control: **Residual Herbicide Plus Roundup WeatherMAX®**	Use the proper Roundup Ready RATE™ of Bullet®, Degree®, Degree Xtra®, Harness®, Harness Xtra, Harness Xtra 5.6L, Micro-Tech™, or Lariat® (no post) as defined in the table below and the individual product labels, either pre or postemergence to the crop.** Follow with Roundup WeatherMAX at 16 to 22 oz/A post sequentially after preemergence application or tank-mixed in-crop with the residual. Applications should be made before weeds exceed 4" in height. **Roundup Ready RATEs***** Harness 1.5 Pints Degree 3.0 Pints Harness Xtra 1.2 Quarts Harness Xtra 5.6L 1.5 Quarts Degree Xtra 2.0 Quarts Micro-Tech 2.0 Quarts Lariat 2.0 Quarts Bullet 2.0 Quarts	Use full labeled rate of residual when application is 14 days or more prior to planting or when tough grasses are present, e.g., barnyardgrass, shattercane, seedling johnsongrass, sandbur. Use a minimum of 2.5 pt/A of Harness on woolly cupgrass and wild proso millet. Products containing atrazine will provide improved control of cocklebur, giant ragweed, *Palmer Amaranth* and morningglory. Tank-mix products such as 2,4-D, dicamba or Status® herbicide with Roundup WeatherMAX for control of glyphosate-resistant marestail (horseweed), *Palmer Amaranth* and other difficult-to-control weeds. Use 22 to 32 oz/A of Roundup WeatherMAX* when morningglory or perennial weeds are present or when broadleaf weeds are 4" in height or taller.
For use where total postemergence programs are effective and sustainable: **Roundup WeatherMAX Sequential**	Apply Roundup WeatherMAX at 16 to 22 oz/A before weeds exceed 4" in height and follow with a second application at 16 to 22 oz/A for an additional flush of weeds before they exceed 4" in height.	Use 22 to 32 oz/A of Roundup WeatherMAX when morningglory or perennial weeds are present. Tank-mix products such as 2,4-D, dicamba or Status herbicide with Roundup WeatherMAX for control of glyphosate-resistant marestail (horseweed), *Palmer Amaranth* and other difficult-to-control weeds.
Maximum Use Rates For Roundup WeatherMAX	**Products with Roundup Ready 2 Technology In-crop:** • 32 oz/A per single application • Total: 64 oz/A from emergence through 48" height of corn, drop nozzles must be used from 30" to 48" corn.	**Products with Roundup Ready 2 Technology Total Season:** The combined total of preplant, in-crop and preharvest applications of Roundup WeatherMAX can not exceed 5.3 qt/A. The combined total of in-crop and preharvest applications can not exceed 66 oz/A.

*If using another Roundup agricultural herbicide, you must refer to the label booklet or Roundup Ready Corn 2 Technology supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX®, application rates are the same as for Roundup WeatherMAX. If using another residual herbicide, follow the labeled use rate instructions applicable to Roundup Ready Corn 2. Follow all pesticide label requirements.

**Atrazine may also be used as a residual herbicide in the Roundup Ready Corn 2 System.

***You may apply up to the full residual herbicide labeled rate for corn.

WEED RESISTANCE MANAGEMENT FOR CORN WITH ROUNDUP READY TECHNOLOGY

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Roundup Ready Technology system.

- Start clean with a burndown herbicide or tillage. Early-season weed control is critical to yield.
- Apply pre-emergence residual herbicides such as Harness Xtra, Degree Xtra or other residual herbicides at the recommended rate.
- Or apply a pre-emergence residual herbicide at the recommended rate tank-mixed with Roundup WeatherMAX® at a minimum of 22 oz/A in-crop before weeds exceed 4" in height.
- Follow with a postemergence in-crop application of Roundup WeatherMAX at a minimum of 22 oz/A for additional weed flushes before they exceed 4" in height.
- Roundup WeatherMAX may be tank-mixed with other herbicides for postemergence weed control.
- Report repeated non-performance to Monsanto or your local retailer.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS IN PRODUCTS WITH ROUNDUP READY TECHNOLOGY

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	Start clean with a burndown program or tillage. -Tank-mix Roundup agricultural herbicides with 2,4-D, or dicamba, according to the label directions. In-crop, tank-mix 22 ounces per acre of Roundup WeatherMAX with Clarity® (8 to 16 fluid ounces per acre) or 2,4-D (0.5 to 1.0 lb active ingredient per acre) from corn emergence to the 5-leaf stage of corn growth (approximately 8" tall). Or tank-mix 22 ounces per acre of Roundup WeatherMAX with 5 ounces per acre of Status® herbicide when the corn is 4" to 36" tall (V2 to V10). Marestail should not exceed 6" in height at the time of in-crop application.
Glyphosate-Resistant *Amaranthus* Species - *Palmer Amaranth* - Waterhemp	Start clean with a burndown program or tillage. Use a residual herbicide such as Harness Xtra, Harness Xtra 5.6L, Degree Xtra or other residual herbicide either preemergence or in-crop for control of *Amaranthus* species. In-crop, tank-mix Roundup WeatherMAX with other herbicides such as 2,4-D, dicamba (Clarity or Banvel®) or Status herbicide to control emerged weeds. Applications of Status herbicide should be made when the corn is between 4" and 36" tall (V2 to V10). Follow all label directions. *Amaranthus* species should not exceed 3" in height at the time of in-crop application.
Glyphosate-Resistant *Ambrosia* Species - Giant Ragweed - Common Ragweed	Start clean with a burndown program or tillage. Use a residual herbicide such as Harness Xtra, Harness Xtra 5.6L, Degree Xtra or other residual herbicide either preemergence or in-crop for control of *Ambrosia* species. In-crop, tank-mix Roundup WeatherMAX with other herbicides such as 2,4-D, dicamba (Clarity or Banvel) or Status herbicide to control emerged weeds. Applications of Status herbicide should be made when the corn is between 4" and 36" tall (V2 to V10). Follow all label directions. *Ambrosia* species should not exceed 3" in height at the time of in-crop application.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown program or tillage. Use a residual herbicide such as Harness Xtra, Harness Xtra 5.6L, Degree Xtra or other residual herbicide containing atrazine preemergence to reduce the competition from seedling johnsongrass prior to the emergence of corn. In-crop, tank-mix Roundup WeatherMAX with a herbicide such as Accent®, Equip™ or Option® for control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.



Genuity™ Bollgard II® and Bollgard® Cotton Descriptions

GENUITY™ BOLLGARD II® COTTON

Genuity™ Bollgard II® cotton contains two distinct insecticidal proteins from *Bacillus thuringiensis (B.t.)* that increase the efficacy and spectrum of control and reduce the chance that resistance will develop to the *B.t.* insecticidal proteins, relative to Bollgard® cotton. Genuity™ Bollgard II® cotton normally provides excellent, season-long control of tobacco budworm, pink bollworm and cotton bollworm. Genuity™ Bollgard II® cotton provides good protection against fall armyworm, beet armyworm, cabbage and soybean loopers and other secondary leaf- or fruit-feeding caterpillar pests of cotton. Applications of insecticides to control these insects are substantially reduced with Genuity™ Bollgard II® cotton.

BOLLGARD® COTTON

Bollgard cotton contains a single insecticidal protein from *B.t.* that provides good control against three major lepidopteran insect pests of cotton. Specifically, Bollgard cotton provides excellent, season-long control of tobacco budworm and pink bollworm, and suppression of cotton bollworm. When the above-mentioned insect larvae feed on Bollgard cotton plants, the *B.t.* protein protects the plants from damage by reducing larval survival. Under high infestation, application of insecticides may be necessary to protect Bollgard cotton.

BOLLGARD PHASE OUT

The U.S. Environmental Protection Agency has mandated the following terms and conditions:*

- Bollgard® cotton may be sold through September 30, 2009. After that date, all sales of Bollgard cotton are prohibited.
- All Bollgard cotton seed must be planted by midnight of July 1, 2010 (the expiration date of the Bollgard cotton registration). After July 1, 2010, planting of Bollgard cotton seed is prohibited. Any Bollgard cotton seed not planted on or before July 1, 2010, must be returned to either the retailer or to Monsanto. No refunds are to be issued on Bollgard cotton seeds bought for planting in 2010 and returned by growers.
- An adequate amount of refuge seed must be purchased for planting an appropriate refuge for Bollgard cotton. Purchase of refuge seed with the Bollgard cotton seed is mandatory, and such seed must be purchased by growers in advance of their receipt of Bollgard cotton seed. Any seed purchased for use as a refuge is non-refundable, unless the proportional amount of Bollgard cotton seed that the refuge seed would have supported is returned at the same time.
- Any order for replacement or additional Bollgard cotton seed for the 2010 planting season, that does not conform to the requirements stated above must be filled with Genuity™ Bollgard II® cotton seed (or other products with current registrations).
- On-farm IRM assessments will be conducted during the planting season.
- In 2010, Bollgard cotton may only be planted in: Alabama, Arkansas, Florida (North of Florida Route 60), Georgia, Kentucky, Louisiana, Maryland, Missouri, Mississippi, North Carolina, South Carolina, Tennessee, Texas (excluding the ten prohibited Texas panhandle counties of: Dallam, Sherman, Hansford, Ochiltree, Lipscomb, Hartley, Moore, Hutchinson, Roberts, and Carson) and Virginia.

*It is a violation of federal law to sell or distribute an unregistered pesticide.

NOTE: Sale or commercial planting of Bollgard® cotton is prohibited in certain states, including: Arizona, California, Colorado, Kansas, New Mexico and Oklahoma.

Sale or planting of Bollgard is prohibited in the Texas counties of: Carson, Dallam, Hansford, Hartley, Hutchison, Lipscomb, Moore, Ochiltree, Roberts, and Sherman.

Sale or commercial planting of both Genuity™ Bollgard II® and Bollgard is prohibited in Hawaii, Puerto Rico, the U.S. Virgin Islands, and in Florida south of Route 60 (near Tampa).

The *B.t. delta endotoxin* protein expressed in this cotton targets certain cotton insect pests. Routine applications of insecticides to control certain insects are usually unnecessary when cotton containing the *B.t. delta endotoxin* protein is planted. However, if insecticide applications are necessary to control certain cotton insect pests, follow all label requirements.

Genuity™ Bollgard II® and Bollgard® Cotton





INSECT RESISTANCE MANAGEMENT (IRM)

Lepidopteran cotton pests have demonstrated the ability to develop resistance to many chemical insecticides. As a preemptive measure, Genuity™ Bollgard II® and Bollgard® cotton must be managed in ways that will retard insect resistance development. These practices are designed to ensure that some lepidopteran populations are not exposed to the *B.t.* proteins so they can maintain susceptibility in select populations. In order to achieve this, refuge cotton that does not contain *B.t.* proteins must be planted.

GENUITY™ BOLLGARD II - DUAL EFFECTIVE DOSE

Resistance management is critical to the long-term viability of our technology and the benefits realized by our farmer customers. 2010 is a transition year for Monsanto *B.t.* cotton products as we shift all U.S. cotton acres toward the two-gene insect control product, Genuity™ Bollgard II® cotton. The move to multiple-gene products, including Genuity™ Bollgard II®, offers dual effective modes of action against target insect pests, increasing the longevity of the technology.

INTEGRATED PEST MANAGEMENT (IPM)

Integrated Pest Management (IPM) is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This information is used to manage pests in a manner that is least harmful to people, property and the environment.

Prevention

Using the best agronomic management practices in conjunction with the appropriate cotton varieties will yield the greatest benefits.

Use varieties, seeding rates and planting technologies appropriate for each specific geographical area. As much as possible, manage the crop to avoid plant stress.

- Employ appropriate scouting techniques and treatment decisions to preserve beneficial insects that can provide additional insect pest control.
- Manage for appropriate maturity and harvest schedules. destroy stalks immediately after harvest to avoid regrowth and minimize selection for resistance in late-season infestations.
- Use soil management practices that encourage destruction of over-wintering pupae.

Monitor and Identify

Fields should be carefully monitored for all pests, including cotton bollworms, to determine the need for remedial insecticide treatments. For target pests, scouting techniques and supplemental treatment decisions should take into account the fact that larvae must hatch and feed before they can be affected by the *B.t.* protein(s) in either Genuity™ Bollgard II® or Bollgard cotton. Fields should be scouted regularly, following periods of heavy or sustained egg lay, especially during bloom, to determine if significant larval survival has occurred. Scouting should include a modified whole-plant inspection, including terminals, squares, blooms, bloom tags and small bolls. Larvae larger than 1/4 inch (3- to 4-days old) are generally recognized as survivors that may not be controlled by Genuity™ Bollgard II® or Bollgard cotton.

Read the IRM/Grower Guide prior to planting for information on planting and Insect Resistance Management. If you do not have a copy of this Guide, you may download it at **www.monsanto.com**, or **call 1-800-768-6387** to request a copy by mail.

Control

Monsanto recommends the use of appropriate remedial insecticide treatments to ensure desired levels of control if any cotton insect pest reaches locally established thresholds in Genuity™ Bollgard II® or Bollgard cotton.

Although Genuity™ Bollgard II® and Bollgard cotton will sustain less damage from some of the most troublesome lepidopteran pests, they will not provide protection against non-lepidopteran species. These insects should be monitored and treated with insecticides when necessary, using recommended thresholds. Whenever possible, select insecticides that are least harmful to beneficial insects.

NOTE: In 2010, sale or commercial planting of Bollgard® cotton is prohibited in the following states: Arizona, California, Colorado, Kansas, New Mexico and Oklahoma.

In 2010, sale or planting of Bollgard® is prohibited in the Texas counties of: Carson, Dallam, Hansford, Hartley, Hutchison, Lipscomb, Moore, Ochiltree, Roberts, and Sherman.

In 2010, sale or commercial planting of both Genuity® Bollgard II® and Bollgard® is prohibited in Hawaii, Puerto Rico, and the U.S. Virgin Islands, or in Florida south of Route 60 (near Tampa).

Roundup Ready® Cotton, Genuity™ Bollgard II® with Roundup Ready® Cotton and Bollgard with Roundup Ready Cotton

ROUNDUP READY COTTON

Roundup Ready® cotton varieties contain in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to make in-crop applications of Roundup WeatherMAX® or Roundup PowerMAX® according to label requirements.

GENUITY™ BOLLGARD II WITH ROUNDUP READY COTTON AND BOLLGARD WITH ROUNDUP READY COTTON

Genuity™ Bollgard II® with Roundup Ready® cotton and Bollgard with Roundup Ready varieties offer farmers the benefits of both insect protection and glyphosate tolerance combined in one crop. These varieties exhibit the same insect protection qualities as Genuity™ Bollgard II® and Bollgard cotton and enable farmers to make in-crop applications of Roundup WeatherMAX or Roundup PowerMAX according to label requirements.

MARKET OPTIONS

Gin by-products of cotton containing Monsanto's biotech traits, including cottonseed for feed uses, are fully approved for export to Canada, Japan, Mexico and South Korea. Cottonseed containing Monsanto traits may not be exported for the purpose of planting without a license from Monsanto.

It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted.

RECOMMENDED MANAGEMENT PRACTICES

Managing Roundup Ready cotton, Bollgard with Roundup Ready cotton and Genuity™ Bollgard II® with Roundup Ready® cotton requires that a farmer follow the recommended management practices associated with cotton containing each individual trait. Farmers of Bollgard with Roundup Ready cotton and Genuity™ Bollgard II® with Roundup Ready® cotton varieties must follow the same guidelines for establishing required refuge options, practicing IRM and managing target and non-target pests as described for Bollgard and Genuity™ Bollgard II® cotton in the IRM/Grower Guide.

APPLICATION OF ROUNDUP WEATHERMAX® AND ROUNDUP POWERMAX®

Roundup Ready cotton is genetically improved to provide tolerance to glyphosate, the active ingredient in Roundup agricultural herbicides. Roundup Ready cotton can receive over-the-top applications of Roundup agricultural herbicides only through the four-leaf stage. With the introduction of Genuity™ Roundup Ready® Flex cotton, there is the potential for both Roundup Ready cotton and Genuity™ Roundup Ready® Flex cotton to be used on a farmer's farm. This creates concern for the crop safety of Roundup Ready cotton. Monsanto recommends that farmers:

- Maintain accurate records of which technologies have been planted and where they have been planted.
- Communicate the field plan with other members of their work force to ensure proper applications for each technology.
- Clearly mark fields to indicate which technology has been planted.

TRACK IT. COUNT IT. More than Four, Post-Direct.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and these guidelines to minimize the risk of developing glyphosate-resistant weed populations in a Roundup Ready cotton system:

- Scout fields before and after each burndown and in-crop application.
- Start clean with a burndown herbicide program or tillage.
- Use the right herbicide product at the right rate and right time.
- Add soil residual herbicide(s) and cultural practices as part of a Roundup Ready weed control program.
- In-crop, apply Roundup WeatherMAX at a minimum of 22 oz/A when weeds are less than 6" in height.
- Tank-mix other approved herbicides with Roundup WeatherMAX if necessary for postemergence weed control.
- Clean equipment before moving from field to field to minimize the spread of weed seed (as well as nematodes, insects and other cotton pests).
- Should repeated non-performance occur, report to Monsanto or your local retailer.

WEED CONTROL RECOMMENDATIONS

Weed control in cotton is essential to help maximize both fiber yield and quality potential. Cotton is very sensitive to early-season weed competition, which can result in unacceptable stands and/or reduced yield potential. The Roundup Ready* cotton system provides farmers with the right tools to control weeds before they become competitive.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	Always start clean by planting into a weed-free field using either tillage or a burndown application. In no-till and reduced-till systems, apply a preplant burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A in a tank-mix with dicamba or 2,4-D. See the dicamba and 2,4-D product label for rates and time intervals required between application and cotton planting. State restrictions may apply.	Early-season weed competition can result in unacceptable stands and/or reduced yield potential. This tank-mix is recommended for control and management of glyphosate-resistant marestail (*Conyza sp.*) or other tough-to-control weeds. Burndown application should be made far enough in advance of planting to control existing weeds.
Residual Herbicides	Apply residual herbicide(s) as part of a Roundup Ready cotton weed control program. Use the recommended label rate and timing of the residual herbicide applied. Refer to individual product labels for list of residual herbicides that may be used.	The residual herbicide(s) may be applied as either a preemergence (including preplant incorporated), postemergence, and/or layby application as allowed on the label of the specific product being used.
Over-The-Top through Fourth Leaf	Apply Roundup WeatherMAX over the top from crop emergence through the fourth true-leaf (node) stage (until the fifth true leaf reaches the size of a quarter). Two applications can be made during this period at a maximum rate of 22 oz/A per application. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label for rate recommendations for specific annual weeds.	In-crop over-the-top applications must be at least 10 days apart and the cotton must have at least two nodes of incremental growth between applications. Care should be taken to record growth stage at first application. In situations where the potential for weed infestations is high (including perennial weeds), make the first application early enough to allow a second application before cotton exceeds the fourth true-leaf stage. Over-the-top applications after the fourth true-leaf stage can result in boll loss, delayed maturity, and/or yield loss.
Selective Equipment	After the fourth true-leaf stage through layby, Roundup WeatherMAX may be applied using precision post-directed or hooded sprayers which direct the spray to the base of the cotton plant. Two post-directed applications can be made during this period at a maximum rate of 22 oz/A per application.	Place nozzles in a low horizontal position to permit spray pattern to overlap in the row while contact of spray solution with cotton leaves should be avoided to the maximum extent possible. Excessive foliar contact can result in boll loss, delayed maturity, and/or yield loss. There must be two nodes of growth and at least 10 days between applications.
Preharvest Over-The-Top Applications	Before harvest and after cotton reaches 20% boll-crack, if needed, apply up to 44 oz/A of Roundup WeatherMAX. This treatment is effective in controlling late-season perennial weeds and can improve harvest efficiency.	Applications must be made at least 7 days prior to harvest. Roundup agricultural herbicides are not effective for preharvest cotton regrowth in Roundup Ready cotton. Do not apply Roundup agricultural herbicides preharvest to crops grown for seed under contract at an authorized cotton seed company.

Roundup Ready cotton has excellent vegetative tolerance to Roundup WeatherMAX allowing early-season over-the-top applications. Incomplete reproductive tolerance requires that applications after the 4-leaf (node) stage be properly post-directed.

ATTENTION: Use of Roundup agricultural herbicides in accordance with label directions is expected to result in normal growth of Roundup Ready cotton, however, various environmental conditions, agronomic practices, and other factors make it impossible to eliminate all risks associated with the product, even when applications are made in conformance with the label specifications. In some cases, these factors can result in boll loss, delayed maturity, and/or yield loss.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or Roundup Ready cotton supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX®, application rates are the same as for Roundup WeatherMAX.



RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	Start clean with a burndown herbicide program or tillage. -Tank-mix Roundup agricultural herbicides with dicamba or 2,4-D (consult label for plant back timing). If you have dense stands of marestail, use a preplant residual herbicide at the recommended rate and timing, such as diuron (Direx®) or flumioxazin (Valor®). Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. In-crop, if applying post-directed to glyphosate-resistant marestail, Roundup WeatherMAX can be tank-mixed with other herbicides, such as diuron or MSMA. Marestail should be less than 6" in height at the time of in-crop application.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl®) plus fluometuron or fomesafen (Reflex®) or flumioxazin (Valor) for control of *Amaranthus* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor or other labeled chloracetamide herbicide before *Amaranthus* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Amaranthus* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl) plus fluometuron or fomesafen (Reflex)for control of *Ambrosia* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor before *Ambrosia* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Ambrosia* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown herbicide or tillage. Preplant incorporate a residual herbicide such as pendimethalin or trifluralin for control or suppression of seedling johnsongrass. Apply Roundup WeatherMAX in a tank-mix with herbicides such as SelectMAX®, Assure® II or Poast Plus for the control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.

Genuity™ Roundup Ready® Flex Cotton and Genuity™ Bollgard II® with Roundup Ready® Flex Cotton





GENUITY™ ROUNDUP READY® FLEX COTTON

Genuity™ Roundup Ready® Flex cotton varieties possess improved reproductive tolerance to Roundup® agricultural herbicides. This technology gives farmers the opportunity to make over-the-top broadcast applications of labeled Roundup agricultural herbicides from crop emergence up to seven (7) days prior to harvest.

GENUITY™ BOLLGARD II® WITH ROUNDUP READY® FLEX COTTON

Genuity™ Bollgard II® with Roundup Ready® Flex varieties offer farmers the benefits of both insect protection and glyphosate tolerance combined in one crop. These varieties exhibit the same insect protection qualities as Genuity™ Bollgard II® and are tolerant to over-the-top applications of Roundup WeatherMAX® and Roundup PowerMAX®.

MARKET OPTIONS

Genuity™ Roundup Ready® Flex cotton and Genuity™ Bollgard II® with Roundup Ready Flex cotton have regulatory clearance in the United States, but do not have import approval in all export markets. Processed fractions from these products, including linters, oil, meal, cottonseed and gin trash, must not be exported without all necessary approvals in the importing country. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted.

RECOMMENDED MANAGEMENT PRACTICES

Managing Genuity™ Roundup Ready® Flex cotton and Genuity™ Bollgard II® with Roundup Ready® Flex cotton requires a farmer to follow the recommended management practices associated with cotton containing each individual trait. Farmers of Genuity™ Bollgard II® with Roundup Ready® Flex cotton must follow the same guidelines for establishing required refuge options, practicing IRM and managing target and non-target pests as described for Genuity™ Bollgard II® cotton in the IRM/Grower Guide.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all label requirements and the guidelines below to minimize the risk of developing weed resistance in a Genuity™ Roundup Ready® Flex cotton system:

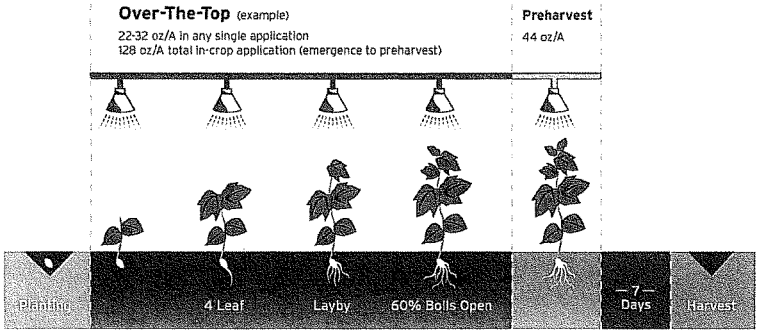
- Scout fields before and after each burndown and in-crop application.
- Start clean with a burndown herbicide program or tillage.
- Use the right herbicide product at the right rate and right time.
- Add soil residual herbicide(s) and cultural practices as part of a Genuity™ Roundup Ready® Flex cotton weed control program.
- In-crop, apply Roundup WeatherMAX at a minimum of 22 oz/A when weeds are 3" to 6" in height.
- Tank-mix other approved herbicides with Roundup WeatherMAX if necessary for postemergence weed control.
- Should repeated non-performance occur, report to Monsanto or your local retailer.
- Clean equipment before moving from field to field to minimize the spread of weed seed (as well as nematodes, insects and other cotton pests).

APPLICATION OF ROUNDUP WEATHERMAX® AND ROUNDUP POWERMAX®

- May be applied over-the-top and/or in-crop, from crop emergence up to 7 days prior to harvest.
- A maximum rate of 32 oz/A per application may be applied using ground application equipment while the maximum is 22 oz/A per application by air.
- There are no growth or timing restrictions for sequential applications.
- Four (4) quarts/A is the total in-crop volume allowed from emergence to 60% open bolls.
- A maximum total volume of 44 oz/A may be applied between layby and 60% open bolls.
- Post-directed equipment may be used to achieve more thorough spray coverage of weeds or if herbicides not labeled for over-the-top application will be tank-mixed with Roundup WeatherMAX or Roundup PowerMAX.

PREHARVEST APPLICATIONS

- Up to 44 oz/A may be applied after cotton reaches 60% open bolls and before harvest, if needed.
- Applications must be made at least 7 days prior to harvest.



CROP SAFETY OF OVER-THE-TOP GLYPHOSATE APPLICATIONS

Monsanto has determined that a combination of components in glyphosate formulations have the potential to cause leaf injury when applied during later stages of crop growth. Roundup WeatherMAX and Roundup PowerMAX are the only Roundup agricultural herbicides labeled and approved for new labeled uses over the top of Genuity™ Roundup Ready® Flex cotton.

Leaf injury may occur if the products are not used according to the product label, used at higher than recommended rates or if overlap of spray occurs in the field. **Farmers must confirm that any glyphosate formulation to be used on Genuity™ Roundup Ready® Flex cotton has been labeled for use on Genuity™ Roundup Ready® Flex cotton and should confirm that it has been tested to demonstrate crop safety.**

WEED CONTROL RECOMMENDATIONS

Weed control in cotton is essential to maximize both fiber yield and quality potential. Cotton is very sensitive to early-season weed competition, which can result in unacceptable stands and/or reduced yield potential. The Genuity™ Roundup Ready® Flex cotton system, with improved reproductive tolerance to Roundup® agricultural herbicides, provides farmers with the right tools to control weeds.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	Always start clean by planting into a weed-free field using either tillage or a burndown application. In no-till and reduced-till systems, apply a preplant burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A in a tank-mix with dicamba or 2,4-D. See the dicamba and 2,4-D product label for rates and time intervals required between application and cotton planting. State restrictions may apply.	Early-season weed competition can result in unacceptable stands and/or reduced yield potential. This tank-mix is recommended for control and management of glyphosate-resistant marestail (*Conyza sp.*) or other tough-to-control weeds. Burndown application should be made far enough in advance of planting to control existing weeds.
Residual Herbicides	Apply approved residual herbicide(s) as part of a Genuity™ Roundup Ready® Flex cotton weed control program. Use the recommended label rate and timing of the residual herbicide applied. Refer to individual product labels for list of residual herbicides that may be used.	The residual herbicide(s) may be applied as either a preemergence (including preplant incorporated), postemergence, and/or layby application as allowed on the label of the specific product being used.
In-Crop Weed Control	Target the first application of Roundup WeatherMAX on 1-2 leaf cotton when weeds are small. Apply a minimum of 22 oz/A of Roundup WeatherMAX in-crop. The need for sequential applications of Roundup WeatherMAX will depend upon the occurrence of subsequent weed flushes. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label booklet for rate recommendations for specific annual weeds.	Early-season weed competition can reduce yield potential in cotton. Select timing of application based on the most difficult to control weed species in your field. Post-direct or hooded sprayers can be used to achieve more thorough spray coverage on weeds.
Preharvest Over-The-Top Applications	Before harvest and after cotton reaches 60% open bolls, if needed, apply up to 44 oz/A of Roundup WeatherMAX. This treatment is effective in controlling late-season perennial weeds.	Applications must be made at least 7 days prior to harvest. Roundup agricultural herbicides are not effective for preharvest cotton regrowth in Genuity™ Roundup Ready® Flex cotton.

*Follow all pesticide label requirements.

**The maximum volume of Roundup WeatherMAX and Roundup PowerMAX® that may be used in a single season is 5.3 quarts per acre.



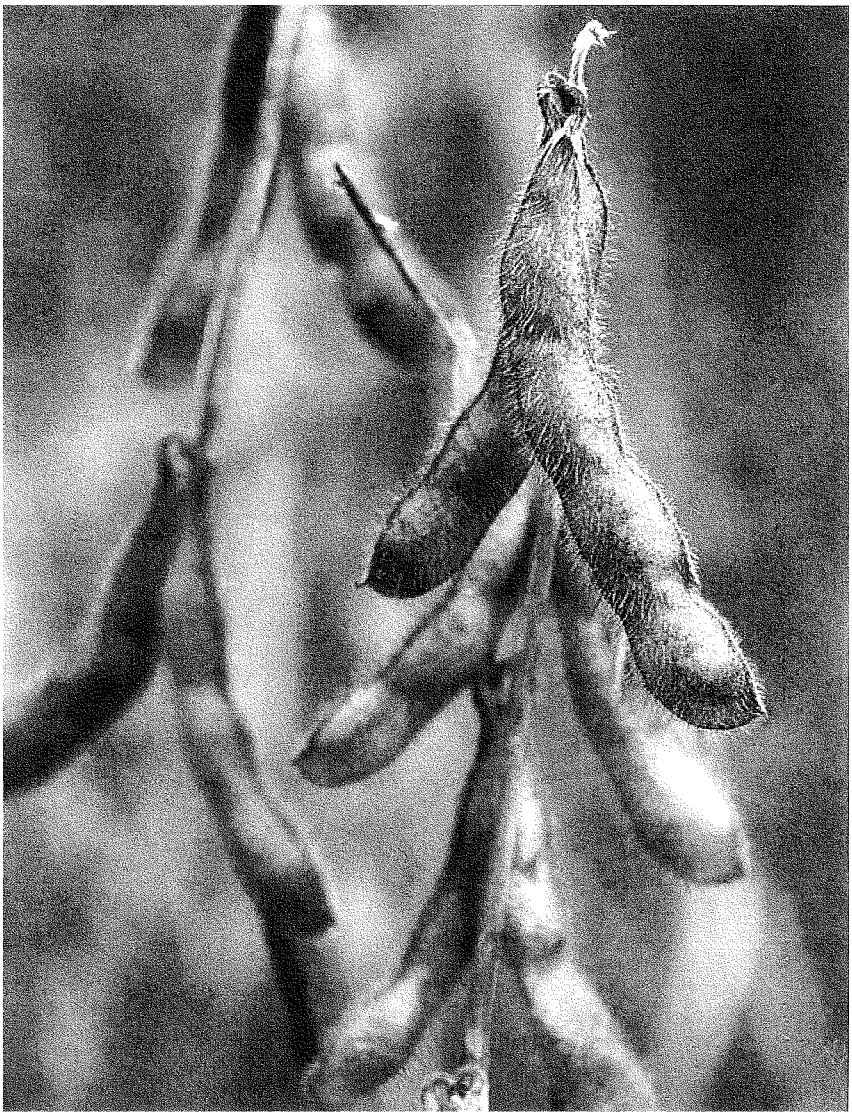


RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	Start clean with a burndown herbicide program or tillage. -Tank-mix Roundup agricultural herbicides with dicamba or 2,4-D (consult label for plant back timing). If you have dense stands of marestail, use a preplant residual herbicide at the recommended rate and timing, such as diuron (Direx®) or flumioxazin (Valor®). Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. In-crop, if applying post-directed to glyphosate-resistant marestail, Roundup WeatherMAX can be tank-mixed with other herbicides, such as diuron or MSMA. Marestail should not exceed 6" in height at the time of in-crop application.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl®) plus fluometuron or fomesafen (Reflex®) or flumioxazin (Valor) for control of *Amaranthus* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor or other labeled chloracetamide herbicide before *Amaranthus* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Amaranthus* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	Start clean with a burndown herbicide program or tillage. Apply a preemergence residual herbicide such as pendimethalin (Prowl) plus fluometuron or fomesafen (Reflex) for control of *Ambrosia* species. In-crop, tank-mix Roundup WeatherMAX at 22 oz/A with metolachlor before *Ambrosia* species emerges. Use Roundup WeatherMAX in-crop, as needed, at a minimum of 22 oz/A to control other weeds. A post-directed application of Roundup WeatherMAX tank-mixed with MSMA and a residual such as diuron (Direx) or flumioxazin (Valor) should be made to control *Ambrosia* species 3" or smaller in height and prevent additional flushes.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown herbicide or tillage. Preplant incorporate a residual herbicide such as pendimethalin or trifluralin for control or suppression of seedling johnsongrass. Apply Roundup WeatherMAX in a tank-mix with herbicides such as SelectMAX®, Assure® II or Poast Plus for the control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.



GENUITY™ ROUNDUP READY 2 YIELD® AND ROUNDUP READY® SOYBEANS





Genuity™ Roundup Ready 2 Yield® and Roundup Ready® soybean varieties contain in-plant tolerance to Roundup® agricultural herbicides. This means you can spray Roundup agricultural herbicides in-crop from emergence through flowering.

Spray labeled Roundup agricultural herbicides over the top from emergence (cracking) through flowering (R2 stage soybeans) for unsurpassed weed control, proven crop safety and maximum yield potential. R2 stage soybeans end when a pod 5 millimeters (3/16") long at one of the four uppermost nodes appears on the main stem along with a fully developed leaf (R3 stage).

WEED CONTROL RECOMMENDATIONS

Starting clean with a weed-free field, and making timely post-emergence in-crop applications, is critical to obtaining excellent weed control and maximum yield potential. The Roundup Ready soybean system provides the flexibility to use the herbicide tools necessary to control weeds at planting and in-crop. Failure to control weeds with the right rate, at the right time and with the right product, can lead to increased weed competition and the potential for decreased yield.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	To start clean in no-till systems, apply a burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A before planting. See the label for appropriate rates by weed species. For control and management of glyphosate-resistant marestail (*Conyza sp.*) or other difficult-to-control weeds present at burndown, apply 22 oz/A of Roundup WeatherMAX in a tank-mix with 1 to 2 pt/A 2,4-D. Make applications 7 to 30 days before planting and before marestail reaches 6" in height.	Always start with a weed-free field. In no-till and reduced-till systems, apply a Roundup WeatherMAX* burndown application to control existing weeds before planting. Adding 2,4-D in the burndown can significantly reduce broadleaf weed pressure at post-emergence timing. Read the 2,4-D product label for time intervals required between application and soybean planting.
Residual Herbicide Plus Roundup WeatherMAX	Use the recommended label rate of a soil-applied residual herbicide applied preemergence to soybeans as defined in the individual product's labeling. The residual product may be tank-mixed with Roundup WeatherMAX at burndown. Refer to individual product labels for list of residual herbicides that may be used. Follow with 22 oz/A Roundup WeatherMAX in-crop when weeds are 2" to 8" tall. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label for rate recommendations for specific annual weeds. Crop rotation following Genuity™ Roundup Ready 2 Yield® and Roundup Ready soybeans is strongly encouraged. Use of a residual herbicide is encouraged especially if the cropping system is a continuous Roundup Ready system.	A residual program is encouraged when agronomic conditions favor the practice. Reducing Roundup WeatherMAX rate when tank-mixing with a residual or use of premixes utilizing a reduced rate of glyphosate (such as Extreme®) is not recommended. If the in-crop application is delayed and weeds are larger, apply a higher rate of Roundup WeatherMAX.
Roundup WeatherMAX	Apply a minimum of 22 oz/A of Roundup WeatherMAX** in-crop when weeds are 2" to 8" tall. Refer to the "Annual Weeds Rate Table" in the Roundup WeatherMAX label for rate recommendations for specific annual weeds. Choose the rate to control the most difficult-to-control weed in your field. A sequential application of this product may be required to control new flushes of weeds in the Roundup Ready soybean crop. If a sequential application is necessary, apply 16 to 22 oz/A of Roundup WeatherMAX** when weeds are 3" to 6" tall.	In-crop application of Roundup WeatherMAX provides control of labeled weeds. For best results, apply 3 to 4 weeks after planting or when weeds are less than 8" tall. If initial application is delayed and weeds are larger, apply a higher labeled rate of Roundup WeatherMAX.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or Genuity™ Roundup Ready 2 Yield® soybean or Roundup Ready soybean supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GENUITY™ ROUNDUP READY 2 YIELD® AND ROUNDUP READY® SOYBEANS

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Glyphosate-Tolerant Volunteer Corn	Tank-mix Roundup WeatherMAX® with 6 to 12 oz/A of Select Max™ and apply to 4" to 36" glyphosate-tolerant volunteer corn.	Choose your Roundup WeatherMAX rate based on the weed species and size listed in the "Annual Weeds Rate Table" of the Roundup WeatherMAX Label.
Maximum Use Rates for Roundup WeatherMAX	**In-Crop:** • 44 oz/A per single application • 44 oz/A during flowering • 64 oz/A emergence through flowering (R2 stage soybeans) **Preharvest:** • 22 oz/A application	**Total Season:** The combined total of preplant, in-crop and preharvest applications of Roundup WeatherMAX can not exceed 5.3 qt/A. The combined total of in-crop and preharvest applications can not exceed 64 oz/A.

*Follow all pesticide label requirements.

Herbicide products sold by Monsanto for use over the top of soybeans with Genuity™ Roundup Ready 2 Yield® Technology for the 2010 crop season are as follows:

- Roundup WeatherMAX
- Roundup PowerMAX

WEED CONTROL RECOMMENDATIONS

KEY WEEDS	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Weeds that Tend to Have Multiple Emergence Events	Where dense stands of weed species such as common lambsquarters, tall and common waterhemp, *Palmer Amaranth*, redroot pigweed, common ragweed, and giant ragweed are expected, the following agronomic practices are recommended: • Start clean with tillage or burndown in no-till and reduced till systems. Include 2,4-D in the burndown. • Plant soybeans in narrow rows (<20"). • Use a pre-plant residual herbicide. • Use the right rate of Roundup WeatherMAX at the right time (proper weed size).	Weeds such as lambsquarters, waterhemp, pigweed, and giant ragweed tend to emerge throughout the season. Sequential Roundup WeatherMAX applications or the addition of a soil residual herbicide may be required for control of subsequent weed flushes.
Difficult-to-Control Weeds	Black nightshade, velvetleaf, waterhemp, morningglory, lambsquarters, Florida pusley, giant ragweed, Pennsylvania smartweed, groundcherry, hemp sesbania and spurred anoda are difficult-to-control weeds. Please refer to the Roundup agricultural herbicide label for specific rates and weed sizes for control of these weeds.	These weed species require special attention be paid to Roundup WeatherMAX rate and application timing (proper weed size) to obtain excellent weed control. A sequential application may be required if a new weed flush occurs, especially in soybeans planted in wide rows (>20").
Perennial Weeds	An in-crop application of 22 to 44 oz/A of Roundup WeatherMAX** will provide suppression and/or control of nutsedge and perennial weeds like Canada thistle, field bindweed, hemp dogbane, horsenettle, johnsongrass, milkweed, quackgrass, etc.	For additional information on perennial weeds, see the "Perennial Weeds Rate Table" in the label booklet for Roundup WeatherMAX. For best control, allow perennials to achieve at least 6" or more of growth before spraying.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or Roundup Ready Soybean or Genuity™ Roundup Ready 2 Yield® Soybean supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Roundup Ready Soybean System:

- Crop rotation is strongly encouraged.
- Scout fields before and after each burndown and in-crop application.



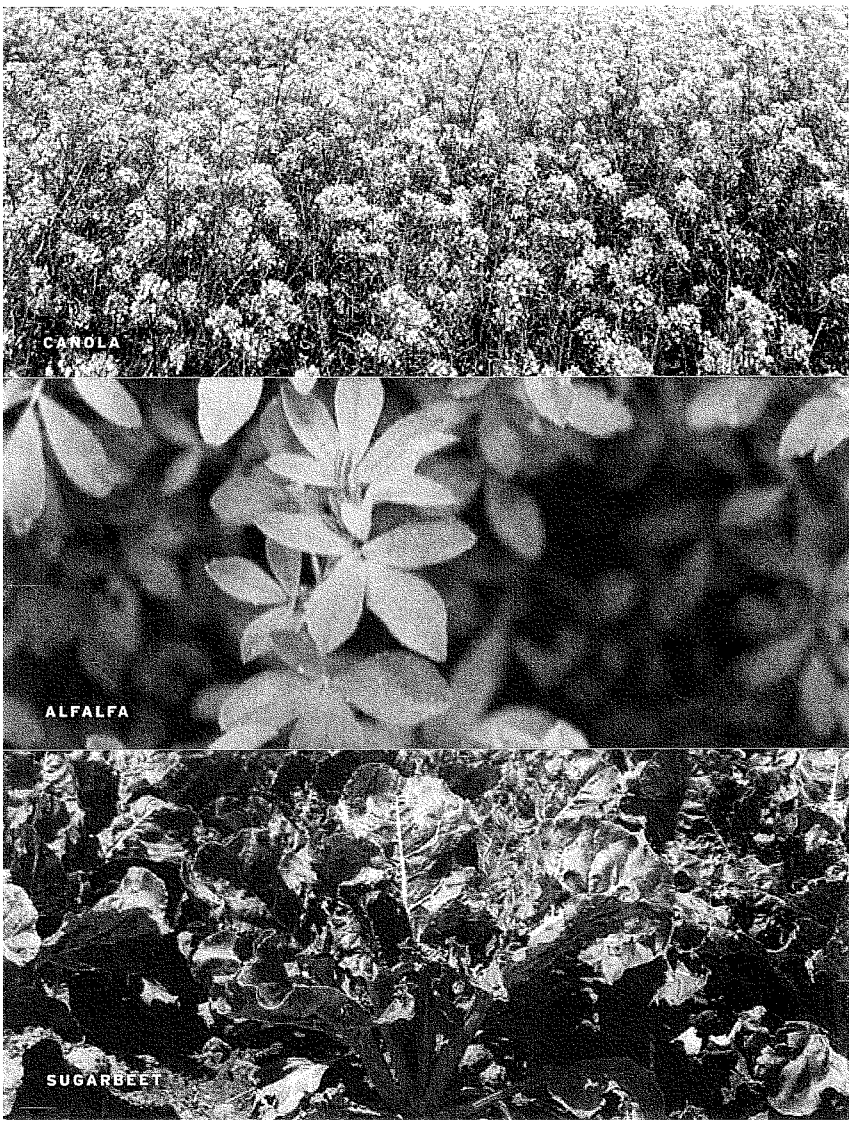
- Start clean with a burndown herbicide or tillage.
  - Tank-mix with 2,4-D to control glyphosate-resistant marestail or other tough-to-control broadleaf weeds.
- Use the recommended label rate of a soil-applied residual herbicide such as INTRRO®, Valor®, Valor XLT® or Gangster®.
- In-crop, apply Roundup WeatherMAX at a minimum of 22 oz/A before weeds exceed 8" in height.
- If an additional flush of weeds occurs, a sequential application of Roundup WeatherMAX at 22 oz/A may be needed before weeds exceed 6" in height.
- Refer to individual product labels for a list of recommended tank-mix partners.
- Clean equipment before moving from field to field to minimize the spread of weed seed.
- Report repeated non-performance to Monsanto or your local retailer.

RECOMMENDATIONS FOR MANAGING GLYPHOSATE-RESISTANT WEEDS

WEEDS	INSTRUCTIONS AND USE RATES*
Glyphosate-Resistant Marestail (Horseweed)	**Preplant:** Apply a tank-mixture of 22 oz/A Roundup WeatherMAX® with 1 pt/A 2,4-D before marestail exceeds 6" in height. See the 2,4-D product label for time intervals required between application and planting. **In-crop:** It is strongly encouraged that marestail should be controlled prior to planting using recommended preplant burndown treatments. In-crop, apply a tank-mixture of 22 oz/A Roundup WeatherMAX with 0.3 oz/A FirstRate®. This treatment should be used as a salvage treatment only for a marestail infestation that was not controlled preplant. Application should be made between full emergence of the first trifoliate leaf and 50% flowering stage of soybeans. At the time of treatment, marestail should not exceed 6" in height.
Glyphosate-Resistant *Amaranthus* Species **- *Palmer Amaranth*** **- Waterhemp**	**Preplant:** Apply a tank-mix of 22 oz/A Roundup WeatherMAX with a preemergence residual herbicide such as alachlor (INTRRO®), flumioxazin (Valor®) or another residual herbicide for preemergence control of *Amaranthus* species. 2,4-D may be added to the tank-mix to help control emerged *Amaranthus* species and other broadleaf weeds preplant only. Follow label instructions regarding application timing relative to soybean planting. **In-crop:** It is strongly encouraged that a preemergence residual product be used to control *Amaranthus* species prior to emergence. If there is emerged *Amaranthus* in-crop, apply a tank-mixture of 22 oz/A Roundup WeatherMAX with a postemergence product with activity on *Amaranthus* such as lactofen (Cobra®), fomesafen (Flexstar®) or cloransulam (FirstRate). Applications should be made on emerged *Amaranthus* that does not exceed 3" in height. Read and follow all product label instructions. It is likely that visual soybean injury will occur with these tank-mixtures.
Glyphosate-Resistant *Ambrosia* Species **- Giant Ragweed** **- Common Ragweed**	**Preplant:** Apply a tank-mix of 22 oz/A Roundup WeatherMAX with a preemergence residual herbicide such as cloransulam (FirstRate) or cloransulam + flumioxazin (Gangster®) or another residual herbicide for preemergence control of *Ambrosia* species. 2,4-D may be added to the tank-mix to help control emerged *Ambrosia* species and other broadleaf weeds preplant only. Follow label instructions regarding application timing relative to soybean planting. **In-crop:** It is strongly encouraged that a preemergence residual product be used to control *Ambrosia* species prior to emergence. If there is emerged *Ambrosia* in-crop, apply a tank-mixture of 22 oz/A Roundup WeatherMAX with a postemergence product with activity on *Ambrosia* such as lactofen (Cobra) or fomesafen (Flexstar). Applications should be made on emerged *Ambrosia* that does not exceed 3" in height. Read and follow all product label instructions. It is likely that visual soybean injury will occur with these tank-mixtures.
Glyphosate-Resistant Johnsongrass	Start clean with a burndown herbicide or tillage. Preplant incorporate a residual herbicide such as pendimethalin or trifluralin for control or suppression of seedling johnsongrass. Apply Roundup WeatherMAX in a tank-mix with herbicides such as SelectMAX®, Assure® II or Poast Plus for the control of emerged weeds including seedling and rhizome johnsongrass. Follow all label directions of tank-mix partners, especially those related to weed size.

In certain areas, Italian ryegrass is known to be resistant to glyphosate. For control recommendations, refer to **www.weedresistancemanagement.com** or call 1-800-768-6387. When approved, supplemental labeling for specific herbicide products can also be viewed on **www.cdms.net** or **www.greenbook.net.**

*Follow all pesticide label requirements.


CANOLA
ALFALFA
SUGARBEET

GENUITY™ ROUNDUP READY® ALFALFA

ATTENTION: Pursuant to a Court Order issued on May 3, 2007, Genuity™ Roundup Ready® alfalfa seed **CAN NOT be commercially sold or planted** until further administrative regulatory actions are completed. For more information, and the latest updates on Genuity™ Roundup Ready® alfalfa, go to www.roundupreadyalfalfa.com.



Genuity™ Roundup Ready® alfalfa varieties have in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to apply labeled Roundup agricultural herbicides up to 5 days before cutting for unsurpassed weed control, excellent crop safety and preservation of forage quality potential.

Hay and Forage Management Practices

Genuity™ Roundup Ready® alfalfa must be managed for high quality hay/forage production, including timely cutting to promote high forage quality (i.e. before 10% bloom) and to prevent seed development. In geographies where conventional alfalfa seed production is intermingled with forage production and the agronomic conditions (climate and water/irrigation availability) are such that forage alfalfa is allowed to stand and flower late in the season, Genuity™ Roundup Ready® alfalfa must be harvested at or before 10% bloom to minimize potential pollen flow from hay to common or conventional alfalfa seed production. Farmers who are unwilling to or who can not make this commitment to stewardship should not continue to grow Genuity™ Roundup Ready® alfalfa.

Genuity™ Roundup Ready® alfalfa varieties have excellent tolerance to over-the-top applications of labeled Roundup agricultural herbicides. An in-crop weed control program using Roundup WeatherMAX® or Roundup PowerMAX® will provide excellent weed control in most situations. A residual herbicide labeled for use in alfalfa may also be applied postemergence in alfalfa. Contact a Monsanto Representative, local crop advisor or extension specialist to determine the best option for your situation.

Stand Takeout and Volunteer Management

Crop rotations can be divided into two main groups, alfalfa rotated to: 1) grass crops (e.g. corn and cereal crops); and 2) broadleaf crops. More herbicide alternatives exist for management of volunteer alfalfa in grass crops. The recommended steps for controlling volunteer Genuity™ Roundup Ready® alfalfa are:

- Diligent Stand Takeout
- Start Clean
- Plan for Success
- Timely Execution

DILIGENT STAND TAKEOUT

Use appropriate, commercially available herbicide treatments alone for reduced tillage systems or in combination with tillage to terminate the Genuity™ Roundup Ready® alfalfa stand. Refer to your regional technical bulletin for specific stand takeout recommendations. **NOTE:** Roundup® agricultural herbicides are **not** effective for terminating Genuity™ Roundup Ready® alfalfa stands.

START CLEAN

If necessary, utilize tillage and/or additional herbicide application(s) after stand takeout, and before planting of the subsequent rotational crop to manage any newly emerged or surviving alfalfa.

PLAN FOR SUCCESS

Rotate the crops with known and available mechanical or herbicidal methods for managing volunteer alfalfa, keeping in mind that Roundup agricultural herbicides will not terminate Genuity™ Roundup Ready® alfalfa stands.

- Rotations to certain broadleaf crops are not advisable if the farmer is not willing to implement recommended stand termination practices.
- In the event that no known mechanical or herbicidal methods are available to manage volunteer alfalfa in the desired rotational crop, it is suggested that a crop with established volunteer alfalfa management practices be introduced into the rotation.

TIMELY EXECUTION

Implement in-crop mechanical or herbicide treatments for managing alfalfa volunteers in a timely manner; that is, before the volunteers become too large to control or begin to compete with the rotational crop.

Planting Requirements

Genuity™ Roundup Ready® alfalfa is not permitted to be planted in any wildlife feed plots.

Stewardship

All Genuity™ Roundup Ready® alfalfa farmers shall sign the Monsanto Technology/Stewardship Agreement (MTSA) limited-use license application which provides the terms and conditions for the authorized use of the product. Due to special circumstances, alfalfa farmers in the Imperial Valley of California will also sign an Imperial Valley Use Agreement (IVUA) with specific stewardship commitments. The MTSA or IVUA must be completed before purchase or use of seed.

Both the MTSA or IVUA explicitly prohibit all forms of commercial seed harvest on the stand. Every alfalfa farmer producing seed of Genuity™ Roundup Ready® alfalfa must possess an additional, separate and distinct seed farmer contract to produce Genuity™ Roundup Ready® alfalfa seed. Genuity™ Roundup Ready® alfalfa seed may not be planted outside of the United States, or for the production of seed or sprouts.

Any product produced from a Genuity™ Roundup Ready® alfalfa crop or seed, including hay and hay products, must be labeled and may only be used, exported to, processed or sold in countries where regulatory approvals have been granted. It is a violation of national and international laws to move material containing biotech traits across boundaries into nations where import is not permitted.

Pursuant to a Court Order issued on May 3, 2007, Genuity™ Roundup Ready® alfalfa farmers must adhere to the requirements set out in the December 18, 2007 USDA Administrative Order **(http://www.aphis.usda.gov/brs/pdf/RRA_AB_final.pdf)** until the USDA completes its regulatory process.

These requirements include, but are not limited to:

- Pollinators shall not be added to Genuity™ Roundup Ready® alfalfa fields grown only for hay production.
- Farm equipment used in Genuity™ Roundup Ready® alfalfa production shall be properly cleaned after use.
- Genuity™ Roundup Ready® alfalfa shall be handled and clearly identified to minimize commingling after harvest.

For additional information visit the USDA website:
http://www.aphis.usda.gov/biotechnology/alfalfa_history.shtml

For more information and the latest updates on Genuity™ Roundup Ready® alfalfa, go to **http://www.roundupreadyalfalfa.com**

To meet sales reporting requirements, the seed supplier is required to identify and list all Genuity™ Roundup Ready® alfalfa field locations. Therefore, all farmers MUST PROVIDE their seed supplier with the GPS coordinates of all their Genuity™ Roundup Ready® alfalfa fields.



WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Genuity™ Roundup Ready® alfalfa system:

- Scout fields before and after each herbicide application.
- Use the right herbicide product at the right rate and at the right time.
- To control flushes of weeds in established alfalfa, make applications of Roundup WeatherMAX® or Roundup PowerMAX® herbicide at 22 to 44 oz/A before weeds exceed 6" in height, up to 5 days before cutting.
- Use other approved herbicide products tank-mixed or in sequence with Roundup agricultural herbicide if appropriate for the weed spectrum present as part of a Genuity™ Roundup Ready® alfalfa weed control program.
- Report repeated non-performance to Monsanto or your local retailer.

WEED CONTROL RECOMMENDATIONS

In established stands, to preserve the quality potential of forage and hay, applications should be made after weeds have emerged but before alfalfa re-growth interferes with application spray coverage of the target weeds.

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Established Stands	After the first harvest of a newly established stand, up to 44 oz/A of Roundup WeatherMAX®** herbicide per cutting may be applied up to 5 days before each subsequent cutting. The combined total per year for all in-crop applications in established stands must not exceed 132 oz/A (4.1 qt/A) of Roundup WeatherMAX.	Applications between cuttings may be applied as a single application or in multiple applications (e.g. 2 applications of 22 oz/A). Sequential applications should be at least 7 days apart.
Weeds Controlled	For specific application rates and instructions for control of various annual and perennial weeds, refer to the Roundup WeatherMAX** herbicide label booklet. Some weeds with multiple germination times or suppressed (stunted) weeds may require a second application of Roundup WeatherMAX** herbicide for complete control. For some perennial weeds, repeated applications may be required to eliminate crop competition throughout the growing season.	In addition to those weeds listed in the Roundup WeatherMAX® label booklets, this product will suppress or control the parasitic weed, dodder (*Cuscuta spp.*) in Genuity™ Roundup Ready® alfalfa. Repeat applications may be necessary for complete control. For tough-to-control weeds or weeds not controlled by Roundup® agricultural herbicides use labeled rates of other approved herbicides, alone or in tank-mixtures, with Roundup agricultural herbicides.
Maximum Use Rates	**In-Crop:** • 44 oz/A per single application. • Established Stand Total: 44 oz/A per cutting up to 5 days before harvest.	**Total Per Year:** The combined total per year for all in-crop applications in established stands must not exceed 132 oz/A (4.1 qt/A) of Roundup WeatherMAX.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or separately published Genuity™ Roundup Ready® alfalfa supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GENUITY™ ROUNDUP READY® SPRING CANOLA

Genuity™ Roundup Ready® spring canola hybrids contain in-plant tolerance to Roundup agricultural herbicides, enabling farmers to apply Roundup® agricultural herbicides over the top of Genuity™ Roundup Ready® spring canola anytime from emergence through the 6-leaf stage of development.

The introduction of the Roundup Ready® trait into leading spring canola hybrids and varieties gives farmers the opportunity for unsurpassed weed control, proven crop safety and maximum profit potential. With Genuity™ Roundup Ready® spring canola, farmers have the weed management tool necessary to improve spring canola profitability, while providing a viable rotational crop to help break pest and disease cycles in cereal-growing areas.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Genuity™ Roundup Ready® spring canola system:

- Scout fields before and after each burndown and in-crop application.
- Start clean with a burndown herbicide or tillage.
- In-crop, apply Roundup WeatherMAX® herbicide before weeds exceed 3" in height.
- A sequential application of Roundup WeatherMAX herbicide may be needed.
- Clean equipment before moving from field to field to minimize the spread of weed seed.
- Report repeated non-performance to Monsanto or your local retailer.

WEED CONTROL RECOMMENDATIONS (SPRING-SEEDED)

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Two-Pass Program– For Annual and Perennial Weed Control	For broad-spectrum control of annual and perennial weeds, use an initial application of 11 oz/A of Roundup WeatherMAX**, in 5 to 10 gal/A water volume. No surfactant is required. Make a second application of 11 oz/A of Roundup WeatherMAX** no less than 10 days after initial application up to the 6-leaf stage (prebolting). Do not exceed 11 oz/A per application.	Spray when canola is at the 0- to 6-leaf stage of growth. To maximize yield potential, spray Genuity™ Roundup Ready® spring canola at the 1- to 3-leaf stage to eliminate competing weeds. Short-term yellowing may occur with later applications, with little effect on crop growth, maturity, or yield. Wait a minimum of 10 days between applications. Two applications of Roundup WeatherMAX will: • Control late flushes of annual weeds such as foxtail, pigweed, and wild mustard. • Provide season-long suppression of Canada thistle, quackgrass, and perennial sow thistle. • Provide better yields by eliminating competition from both annuals and hard-to-control perennials.
Single Application– For Annual Weed Control	For broad-spectrum control of annual and easy-to-control perennial weeds, make a single application of 16 oz/A of Roundup WeatherMAX.**	For best results, spray Genuity™ Roundup Ready® spring canola at the 2- to 3-leaf stage. Can be applied up to 6-leaf stage; yellowing may occur with later application with little effect on crop growth, maturity, or yield. No additional over-the-top applications can be made.
Maximum Use Rate For Roundup WeatherMAX	Two over-the-top applications: Do not exceed 11 oz/A per application. Single over-the-top applications: Do not exceed 16 oz/A. No additional application can be made.	

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or separately published Genuity™ Roundup Ready® canola supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GENUITY™ ROUNDUP READY™ WINTER CANOLA



Genuity™ Roundup Ready® winter canola varieties have been developed for seeding in the fall and harvesting the following spring/summer.

Genuity™ Roundup Ready® winter canola varieties contain in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to apply Roundup agricultural herbicides over the top of Genuity™ Roundup Ready® winter canola from crop emergence to the pre-bolting stage. The introduction of the Roundup Ready trait into winter canola varieties gives farmers the opportunity of unsurpassed weed control, crop safety and maximum yield potential. Genuity™ Roundup Ready® winter canola offers farmers an important option as a rotational crop in traditional monoculture winter wheat production areas. Introducing crop rotation is an important factor in reducing pest cycles, including weed and disease problems.

WEED RESISTANCE MANAGEMENT GUIDELINES

Follow the same guidelines as stated for spring canola.

WEED CONTROL RECOMMENDATIONS (WINTER-SEEDED)

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Sequential Applications	The two-pass program gives the greatest flexibility in controlling late emerging weeds. For broad-spectrum weed control, apply 11 to 22 oz/A of Roundup WeatherMAX** herbicide to 2-leaf or larger Genuity™ Roundup Ready® winter canola in the fall. Use 5 to 10 gallons/A water volume. Do not add surfactants. Apply a second application of Roundup WeatherMAX** at 11 to 22 oz/A at a minimum interval of 60 days after the first application and before bolting in the spring. Do not exceed 22 oz/A per application.	Spray when Genuity™ Roundup Ready® winter canola is at the 2-3 leaf stage of growth. Early applications can eliminate competing weeds and improve yield potential. Two applications of Roundup WeatherMAX will provide control of early emerging annual weeds and winter emerging weeds such as downy brome, cheat and jointed goatgrass.
Single Application	For broad-spectrum control of annual and easy-to-control perennial weeds, make a single application of 16 to 22 oz/A of Roundup WeatherMAX**, preferably in the fall.	For best results, spray Genuity™ Roundup Ready® winter canola at the 2-3 leaf stage and when weeds are small and actively growing. Applications must be made prior to bolting. Use the higher rate in the range when weed densities are high, when weeds have over wintered or when weeds become large and well established.
Maximum Use Rate for Roundup WeatherMAX	Any single over-the-top application of Roundup WeatherMAX** should not exceed 22 oz/A. No more than two over-the-top applications may be made from crop emergence to canopy closure prior to bolting in the spring.	Applications of greater than 16 fluid ounces/A prior to the 6-leaf stage may result in temporary yellowing and/or growth reduction.

*Follow all pesticide label requirements.

**If using another Roundup brand herbicide, you must refer to the label booklet or Genuity™ Roundup Ready® winter canola supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

GRAZING

It is recommended that Genuity™ Roundup Ready® winter canola not be grazed. While Genuity™ Roundup Ready® winter canola may provide farmers additional opportunity as a forage for grazing livestock, at the present time insufficient information exists to allow safe and proper grazing recommendations. Preliminary data suggest that excessive grazing can significantly reduce yield, and that careful nitrate management is critical in managing Genuity™ Roundup Ready® winter canola as a forage to limit the risk of livestock nitrate poisoning. State universities are assessing the potential and the instructions for grazing Genuity™ Roundup Ready® winter canola and they will provide grazing management guidelines when their research is completed.

GENUITY™ ROUNDUP READY® SUGARBEETS



Genuity™ Roundup Ready® sugarbeet varieties have in-plant tolerance to Roundup® agricultural herbicides, enabling farmers to apply labeled Roundup agricultural herbicides from planting through 30 days prior to harvest for unsurpassed weed control, excellent crop safety and preservation of yield potential.

MANAGEMENT PRACTICES

Sugarbeets are extremely sensitive to weed competition for light, nutrients and soil moisture. Research on sugarbeet weed control suggests that sugarbeets need to be kept weed-free for the first eight weeks of growth to protect yield potential. Therefore, weeds must be controlled when they are small and before they compete with Genuity™ Roundup Ready® sugarbeets (exceed crop height), that is from less than 2" up to 4" in height, to preserve sugarbeet yield potential. *More than one in-crop herbicide application will be required* to control weed infestations to protect yield potential as Roundup agricultural herbicides have no soil residual activity. Bolting sugarbeets must be rogued or topped in Genuity™ Roundup Ready® sugarbeet fields.

Genuity™ Roundup Ready® sugarbeet varieties have excellent tolerance to over-the-top applications of labeled Roundup agricultural herbicides. A postemergence weed control program using Roundup WeatherMAX® or Roundup PowerMAX® will provide excellent weed control in most situations. A residual herbicide labeled for use in sugarbeets may also be applied preemergence, preplant or postemergence in Genuity™ Roundup Ready® sugarbeets. Contact a Monsanto Representative, local crop advisor or extension specialist to determine the best option for your situation.

WEED RESISTANCE MANAGEMENT FOR GENUITY™ ROUNDUP READY® SUGARBEETS

Follow all pesticide label requirements and the guidelines below to minimize the risk of developing glyphosate-resistant weed populations in a Genuity™ Roundup Ready® sugarbeet system:

- Start clean with tillage and follow-up with a burndown herbicide, such as Roundup WeatherMAX, if needed prior to planting.
- Early-season weed control is critical to protect sugarbeet yield potential. Apply the first in-crop application of Roundup WeatherMAX at a minimum of 22 oz/A while weeds are less than 2" in height.
- Follow with additional postemergence in-crop application of Roundup WeatherMAX at a minimum of 22 oz/A for additional weed flushes before weeds exceed 4" in height.
- Add spray grade ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup® agricultural herbicides to maximize product performance.
- Use mechanical weed control/cultivation and/or residual herbicides where appropriate in your Genuity™ Roundup Ready® sugarbeets.
- Use additional herbicide modes of action/residual herbicides and/or mechanical weed control in other Roundup Ready crops you rotate with Genuity™ Roundup Ready® sugarbeets.
- Report repeated non-performance of Roundup agricultural herbicides to Monsanto or your local retailer.

AGRONOMIC PRINCIPLES IN SUGARBEETS

Sugarbeets are very sensitive to early-season weed competition. It is important to select the appropriate herbicide product, application rate and timing to minimize weed competition to protect yields. The Genuity™ Roundup Ready® sugarbeet system provides a mechanism to control weeds at planting and once Genuity™ Roundup Ready® sugarbeets emerge. Failure to control weeds with the right rate, at the right time and with the right product, can lead to increased weed competition, weed escapes and the potential for decreased yields. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended as they may result in crop injury and reduced pest control or antagonism.

PLANTING REQUIREMENTS

Genuity™ Roundup Ready® sugarbeets are not permitted to be planted in any wildlife feed plots.

STEWARDSHIP

All Genuity™ Roundup Ready® sugarbeet farmers shall sign the Monsanto Technology/Stewardship Agreement (MTSA) limited-use license application which provides the terms and conditions for the authorized use of the product. The MTSA must be signed and approved prior to purchase or use of seed.

WEED CONTROL RECOMMENDATIONS

PROGRAM	INSTRUCTIONS AND USE RATES*	ADDITIONAL INFORMATION
Preplant Burndown	After preplant tillage or bedding operations have been completed, a preplant burndown application of Roundup WeatherMAX®** at 22 to 44 oz/A may be applied to control weeds that have germinated after tillage and prior to planting. See the label for appropriate rates by weed species and weed size.	Always utilize tillage to start with a weed-free field.
Over-The-Top Applications up to eight-leaf Genuity™ Roundup Ready® Sugarbeets	Up to two applications of Roundup agricultural herbicides may be made prior to the 8-leaf stage of Genuity™ Roundup Ready® sugarbeets. The first application of 22 to 32 oz/A of Roundup WeatherMAX** should be made when weeds are less than 2" in height to protect yield potential. Make an additional application of 22 to 32 oz/A of Roundup WeatherMAX before weeds exceed 4" in height. Maximum in-crop Roundup WeatherMAX prior to 8-leaf stage must not exceed 56 oz/A.	Sugarbeets are sensitive to weed competition and can lose yield rapidly if weeds are not controlled early. More than one in-crop Roundup WeatherMAX application will be required to control weed infestations to protect yield potential as Roundup agricultural herbicides have no soil residual activity. Add ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup agricultural herbicides to maximize product performance. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended. Sequential applications should be at least 10 days apart.
Over-The-Top Applications to greater than eight-leaf Genuity™ Roundup Ready® Sugarbeets	Up to two additional applications of 22 oz/A of Roundup WeatherMAX can be made after the eight-leaf stage up to 30 days prior to harvest. Maximum in-crop Roundup WeatherMAX from 8-leaf stage up until 30 days prior to harvest must not exceed 44 oz/A.	Add ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup agricultural herbicides to maximize product performance. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended. Sequential applications should be at least 10 days apart.
Maximum Use Rates	**In-Crop:** • Two applications of Roundup WeatherMAX prior to the 8-leaf stage of Genuity™ Roundup Ready® sugarbeets - 32 oz/A per single application up to the 8-leaf stage. - Combined maximum of 56 oz/A in-crop prior to the 8-leaf stage • Two applications of Roundup WeatherMAX after the 8-leaf stage up to 30 days prior to harvest - 22 oz/A per single application after the 8-leaf stage. - Combined maximum of 44 oz/A in-crop after the 8-leaf stage until 30 days prior to harvest	**Total Per Year:** The combined total per year for all Roundup WeatherMAX applications including pre-plant must not exceed 5.3 qt/A. Total in-crop application must not exceed 3 qt/A. Add ammonium sulfate at a rate of 17 lbs/100 gallons of spray solution with Roundup agricultural herbicides to maximize product performance. Tank-mixtures of Roundup agricultural herbicides with fungicides, insecticides, micronutrients or foliar fertilizers are not recommended.

*Follow all pesticide label requirements.

**If using another Roundup agricultural herbicide, you must refer to the label booklet or separately published Genuity™ Roundup Ready® sugarbeets supplemental label for that brand to determine appropriate use rates. If using Roundup PowerMAX, application rates are the same as for Roundup WeatherMAX.

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- Saves the equivalent of 585 mature trees
- Reduces solid waste by 35,308 pounds
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Before opening a bag of seed, be sure to read, understand and accept the stewardship requirements, **including applicable refuge requirements for insect resistance management,** for the biotechnology traits expressed in the seed as set forth in the Monsanto Technology Agreement that you sign. By opening and using a bag of seed, you are reaffirming your obligation to comply with the most recent stewardship requirements.

Roundup Ready® Alfalfa seed is currently not for sale or distribution. The movement and use of Roundup Ready® Alfalfa forage is subject to a USDA administrative Order available at http://www.aphis.usda.gov/brs/pdf/RRA_AB_final.pdf.

This stewardship statement applies to all products listed herein except Genuity™ VT Double PRO™, Genuity™ VT Triple PRO™ and Genuity™ SmartStax™. See restrictions related to Genuity™ Double PRO™, Genuity™ VT Triple PRO™ and Genuity™ SmartStax™ below:

Monsanto Company is a member of Excellence Through Stewardship® (ETS). Monsanto products are commercialized in accordance with ETS Product Launch Stewardship Guidance, and in compliance with Monsanto's Policy for Commercialization of Biotechnology-Derived Plant Products in Commodity Crops. This product has been approved for import into key export markets with functioning regulatory systems. Any crop or material produced from this product can only be exported to, or used, processed or sold in countries where all necessary regulatory approvals have been granted. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Growers should talk to their grain handler or product purchaser to confirm their buying position for this product. Excellence Through Stewardship® is a registered trademark of Biotechnology Industry Organization.

IMPORTANT: Grain Marketing and Seed Availability: Genuity™ VT Double PRO™ has received the necessary approvals in the United States, however, as of October 22, 2009, approvals have not been received in certain major corn export markets. **Genuity™ VT Double PRO™** will not be launched and seed will not be available until after import approvals are received in appropriate major corn export markets. **B.t. products, including Genuity™ VT Double PRO™** may not yet be registered in all states. Check with your Monsanto representative for the registration status in your state.

IMPORTANT: Grain Marketing and Seed Availability: Genuity™ VT Triple PRO™ has received the necessary approvals in the United States however, as of October 22, 2009, approval has not been received in all major corn export markets. Monsanto anticipates that all such approvals will be in place for the 2010 growing season. If all approvals are not in place, **Genuity™ VT Triple PRO™** seed will only be available as part of a commercial demonstration program that includes grain marketing stewardship requirements. It is a violation of national and international law to move material containing biotech traits across boundaries into nations where import is not permitted. Consult with your seed representative for current regulatory and stewardship information status.

IMPORTANT: Grain Marketing and Seed Availability: Genuity™ SmartStax™ has received the necessary approvals in the United States, however, as of October 22, 2009, approvals have not been received in certain major corn export markets. **Genuity™ SmartStax™** will not be launched and seed will not be available until after import approvals are received in appropriate major corn export markets. **B.t. products, including Genuity™ SmartStax™** may not yet be registered in all states. Check with your Monsanto representative for the registration status in your state.

Cottonseed containing Monsanto traits may not be exported for the purpose of planting without a license from Monsanto.

Individual results may vary, and performance may vary from location to location and from year to year. This result may not be an indicator of results you may obtain as local growing, soil and weather conditions may vary. Growers should evaluate data from multiple locations and years whenever possible.

Growers may utilize the natural refuge option for varieties containing the Bollgard II® trait in the following states: AL, AR, FL, GA, KS, KY, LA, MD, MS, MO, NC, OK, SC, TN, VA, and most of Texas (excluding the Texas counties of Brewster, Crane, Crockett, Culberson, El Paso, Hudspeth, Jeff Davis, Loving, Pecos, Presidio, Reeves, Terrell, Val Verde, Ward and Winkler). The natural refuge option does not apply to **Bollgard II** cotton grown in areas where pink bollworm is a pest, including CA, AZ, NM, and the above listed Texas counties. It also remains the case that **Bollgard®** and **Bollgard II** cotton cannot be planted south of Highway 60 in Florida, and that **Bollgard** cotton cannot be planted in certain other counties in the Texas panhandle. Refer to the Technology Use Guide and IRM/Grower Guide for additional information regarding Bollgard II, Bollgard, natural refuge and EPA-mandated geographical restrictions on the planting of *B.t.* cotton.

ALWAYS READ AND FOLLOW PESTICIDE LABEL DIRECTIONS. Roundup Ready® crops contain genes that confer tolerance to glyphosate, the active ingredient in Roundup® brand agricultural herbicides. Roundup® brand agricultural herbicides will kill crops that are not tolerant to glyphosate. Degree® and Harness® are not registered in all states. Degree® and Harness® may be subject to use restrictions in some states. Bullet®, Degree Xtra®, Harness®, INTRRO®, Lariat®, and Micro-Tech™ are restricted use pesticides and are not registered in all states. The distribution, sale, or use of an unregistered pesticide is a violation of federal and/or state law and is strictly prohibited. Check with your local Monsanto dealer or representative for the product registration status in your state.

Tank mixtures: The applicable labeling for each product must be in the possession of the user at the time of application. Follow applicable use instructions, including application rates, precautions and restrictions of each product used in the tank mixture. Monsanto has not tested all tank mix product formulations for compatibility or performance other than specifically listed by brand name. Always predetermine the compatibility of tank mixtures by mixing small proportional quantities in advance.

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